Evaluation Report for the Inria Interaction and Visualization Theme

Held in Paris, October 3-5, 2018

This document reports on the findings and observations of the panel of experts convened to evaluate the Inria project teams in the theme Interaction and Visualization The meetings between the panel and the project teams took place in Paris, October 4–5, 2018, preceded by a meeting with Inria staff on October 3.

Panel Composition

The evaluation panel consisted of 15 experts from a broad range of backgrounds and locations. Individual panel members were well chosen, with expertise in all areas covered by the theme. Nine of the experts were from academia, while the other six were from industry and government research centers. This was three more experts than had served on the 2014 panel, with the increase coming entirely from the industry and government sectors, addressing a point made in the 2014 report about the relatively low industrial representation. However, the number of women on the panel remained the same as in 2014, unfortunately decreasing the gender balance. All of the experts were present for the entire meeting and took part actively and enthusiastically in the discussions. The names and affiliations of the experts are:

- Simon Clavet, Ubisoft Montreal, Canada
- Steven Drucker, Microsoft, USA
- Steven Feiner (chair), Columbia University, USA
- James Foley, Georgia Institute of Technology, USA
- Tovi Grossman, University of Toronto, Canada
- Victoria Interrante, University of Minnesota, USA
- Gudrun Klinker, Technische Universität München, Germany
- Jérôme Maillot, Dassault Systèmes, France
- Benoit Maujean, Mikros Image, France
- Jeffrey Nichols, Google, USA
- Ken Perlin, New York University, USA
- Yvonne Rogers, University College London, UK
- Holly Rushmeier, Yale University, USA
- Ariel Shamir, IDC Herzliya, Israel
- Michela Spagnuolo, IMATI CNR, Italy

Evaluation Panel Report Summary

This report presents the panel's evaluation of the seminar, the theme as a whole, and each of the individual project teams. Across the board, we were enormously impressed by all of the teams individually and by the overarching theme that they together comprise. This is a truly exceptional group of world-class researchers doing cutting-edge science, publishing in and providing leadership to the top conferences and journals in their fields, producing influential software embodying their research, collaborating with some of the top academic and industrial researchers elsewhere, and working with and transferring technology to local and international companies. Following an overview of the seminar and the theme, we provide reports on the teams we reviewed, discussing for each team our perception of its strengths and weaknesses, and our recommendations for the future. Overall, we give each of the teams and the entire theme a positive evaluation.

Seminar Organization

The seminar, which was extremely well organized overall, took place over two-and-a-half days, beginning the evening of Wednesday, October 3, with private meetings between the panelists and Inria management, and between the panelists and the president of the evaluation committee. This provided an informative introduction to how we were expected to carry out our evaluation for new panelists and a much appreciated review for those three (Feiner, Interrante, and Shamir) who had participated in the 2014 evaluation.

The first full day of the seminar, Thursday, October 4, began with an overview of the theme by Peter Sturm, followed by 13 half-hour-long presentations of the teams we were reviewing (punctuated by lunch and two coffee breaks), two 15-minute-long presentations of new teams in incubation (LOKI and MFX) formed earlier in 2018 that were not being reviewed, an hour-long private meeting of the panelists, and a working dinner. Reviewing the day during our evening meeting, we made several observations:

These presentations were vital in providing a high-level understanding of the impressive accomplishments of all the teams we were reviewing. However, they resulted in an 11-hour day, not counting breakfast and dinner, further noting that nine of the panelists were six to nine hours off from their home time zones. It is not clear how to address this, other than shortening the individual presentations, increasing the number of days, or splitting the theme into two that would be separately evaluated.

Many of the team presentations did not communicate the “big picture” of what they were doing and the top-level motivation underlying their work. Making this more explicit would have helped differentiate the research directions across the teams when applicable. (Since the schedule is already tightly constrained, perhaps the time needed to do this could be obtained by eliminating from the first day the presentation of slides reviewing each team’s numerical indicators of productivity. Instead, the tables could be provided for the panelists to review on their own, or these slides could be moved to each team’s second-day presentation.)

Similarly, reports were more useful when they said *why* what the team did mattered, rather than simply recounting *what* the team did. In many cases, the main motivations and impacts could have been more clearly stated. In addition, it would have been helpful to have an understandable rationale provided for the choice of each of the five most important publications. More should also be said about long-term vision, not just that a team is going to continue doing what they are doing.

Some of the contributions would be more clearly delineated by stating their relationship to previous work and pointing out what was novel. It was difficult in some cases to tell exactly what was new or to determine whether the researchers were aware of other related work.

We also noted several logistical issues: Copies of the slides for a number of the presentations were also not ready in the morning, making note taking more difficult than it needed to be—Several of us would have appreciated being able to make notes directly on the slides during the presentations. In addition, this theme's graphics-intensive presentations were presented on an older, dim, relatively low-resolution, 4:3 aspect-ratio projector, instead of on a current, bright HD projector that would have made the presentations far easier to view.

The second full day of the seminar, Friday, October 5, was devoted to four two-hour sessions, during each of which three to four teams met in private parallel meetings with a preassigned set of three experts, at least one of whom was from industry. We were in agreement that the assignments had been well thought out, matching panelists to topics appropriate to their expertise.

The report on the 2014 seminar had noted some confusion among the teams that year as to what material they were expected to prepare for these two-hour sessions and pointed out that it was only the night before that the 2014 panel had come up with a set of questions to be communicated to the teams, leaving them little time to prepare answers. Therefore, we were pleased that in the month prior to our arrival, we had been asked to outline a basic structure for these sessions, for timely delivery to the teams, and we agreed, through email, on one that was substantially similar to what had been suggested for future evaluations in the 2014 report:

- 10 minutes for introductions of the team members and panelists;
- 60 minutes for demos (of software or tools) and additional presentations by the project team related to research work, internal/external challenges, and future research directions; and
- 30–40 minutes for detailed questions and feedback about the team's research from the panel.

This would be followed by 10–20 minutes for the experts to discuss in private the team's evaluation and reach some consensus related to the evaluation criteria.

While we thought that this schema worked well, we would suggest that for the next evaluation, a discussion of future research directions be explicitly required, rather than being included as one of a set of topics in a shared bullet point.

The demos given during these sessions were quite successful at explaining team accomplishments. One suggestion that may be worth considering for the next evaluation seminar, although we have not thought through its logistics, would be to have a dedicated plenary demo session (or, perhaps, a demo and poster session). For example, this might take place during a walk-around lunch, dinner, or cocktail. An additional benefit of a dedicated session would be to provide more exposure for junior scientists and PhD students. If this session supplemented, rather than replaced, the demos held during the individual team sessions, it would also allow panelists who didn't attend a particular team session to see demos they would otherwise miss.

Independent of our suggestion of a dedicated demo (or demo and poster) session, we would like to encourage the teams to involve more junior scientists and PhD students in presenting during the two-hour team sessions.

Theme Organization, Coverage, and Internal Collaboration

The Thursday morning presentation by Peter Sturm was an impressive overview of the 13 project teams and two new teams in incubation involved in the broad theme of Interaction and Visualization, setting the stage for the individual team presentations that would follow. The mapping of teams to the areas of Human–Computer Interaction (HCI), Computer Graphics, VIsualization, Virtual Reality (VR), and Geometry Processing, along with additional areas such as BCI and 3D Printing, was enlightening, laying out Inria's well-planned coverage of this theme. We were intrigued by the many inter-team collaborations described in this presentation and in the individual team sessions, whether stand-alone or under the aegis of the two Inria Project Labs, AVATAR and BCI-Lift,

Slides 10–11 of this presentation exposed, at a high level, collaborations evidenced by joint publications between teams in the Interaction and Visualization theme and other teams in all five domains. However, many of the names of these other teams that appear on slide 11 were not cited in the team reports, making it difficult to understand the interactions. Further, only slightly more detail was provided (on slide 11) about intra-domain inter-theme collaborations with the other themes in domain D4. The panel would have liked to learn more about these intra-domain collaborations, Yet we found very little information about these relationships in the individual team synthesis reports—in some cases, only the mention that a collaboration exists, without any details. There are areas addressed by the Interaction and Visualization theme that are also addressed by other themes in D4 (e.g., AR in theme T1 [Vision, Perception and Multimedia Interpretation]), as well as different but complementary areas, Therefore, we strongly suggest encouraging and celebrating these intra-domain inter-theme collaborations, both through a more detailed visualization in the introductory slides, and more information in the team reports.

Members of the panel noted that there were several research areas that would have benefited from more emphasis in this theme:

- *Conversational user interfaces* have become commonplace with the meteoric ascent of commercial implementations: Apple Siri, Amazon Alexa, Google Assistant, and Microsoft Cortana. With the exception of Siri, all were either announced or productized after the last theme evaluation in 2014. However, the panel could not find any mention of research being done in this area, which would seem to be ripe for intra-domain inter-theme collaboration with teams in theme T5 [Language, Speech and Audio].

- *Crowd-powered user interfaces* are of interest, given the existence of Mechanical Turk and similar crowdsourcing marketplaces that can provide interactive access to suitable workers who can perform tasks that are beyond the ability of current AI. While there are teams performing crowdsourced evaluations, we did not see any research on crowd-powered user interfaces.

- *User-centered security*, which addresses the usability of security measures that involve human interaction, is highly relevant to matters of security, privacy, and confidentiality that appear throughout the new Inria Scientific Strategic Plan. While some work has been done on privacy previously in EX-SITU and currently in MINT, this could be a good area to pursue in conjunction with teams in other domains.

- Some research on *interaction for wearables* has been performed by the EX-SITU and HYBRID teams. However, as hardware continues to shrink in size, this is an area that will become increasingly important. *Audio interaction* is also a key area. While there is research by EX-SITU on audio for remote collaboration using wall-sized displays and by IMAGINE on expressive speech for virtual actors, audio for wearable user interfaces does not seem to be addressed, whether to complement graphics or to support eyes-free interaction. There is a strong potential here for intra-domain inter-theme collaboration with teams in theme T5 [Language, Speech and Audio].

- Panel members also noted that relatively little was said about interaction issues related to *cloud and distributed architectures* or *edge computing*. Although collaborations with teams in Domain D3 were mentioned, more information would have been appreciated.

While most of the teams are already taking advantage of Machine Learning (ML), there remain many opportunities for applications of ML to HCI to help make sense of the ever increasing volumes of data being produced by mobile and wearable devices, as well as home sensors. This is especially true in the general area of health and wellness (previously suggested as a topic for greater emphasis in the 2014 report), where diagnosis and treatment of a wide range of ailments are being aggressively pursued by research groups around the world. We recommend explicit discussions about the possibility of further expanding this emphasis.

One panelist remarked on the relative lack of ethnic diversity that was reflected in the presenting teams (and the evaluation panel), in contrast to present-day Paris. It would be good for Inria to try to take a leadership role in encouraging greater involvement of people from underrepresented groups in each of the scientific areas that it explores.

There appear to be some funding issues involving relationships between the different entities for whom team members can work. This can cause problems to arise when interorganizational contracts can't be agreed upon, reflecting an underlying lack of flexibility in how people in different organizations work together in a team.

Several teams noted problems with ineffective administrative and financial software.

Teams should consider how they could participate in the open-source effort recently announced by the Academy of Motion Picture Arts and Sciences for the animation and special effects industries, the Academy Software Foundation (https://www.aswf.io/).

Overall Theme Evaluation

The panel was, across the board, extremely impressed with the quality and productivity of the research teams that we reviewed. As one panelist put it, "I had no idea of how much Inria is doing in the SIGGRAPH and SIGCHI spaces. Amazing." To cite just a few representative metrics, the panel noted that during the four-year evaluation period:

- Ten prestigious ERC grants were in place, six of which were awarded during this period.
- Theme researchers served as Papers Chair of *ACM CHI 2017* (the premier conference on HCI), Technical Papers Chair of *ACM SIGGRAPH 2017* (the premier conference on computer graphics), Papers Chair of *IEEE InfoVis 2018* (the premier conference on information visualization), Program Chair and General Chair of *IEEE VR 2015* and *2016* and Conference Papers Program Chair of *IEEE VR 2018* (the premier conference on VR), General Chair of *IEEE ISMAR 2017* (the premier conference on mixed and augmented reality), and Steering Committee Chair of *IEEE InfoVis* (2016–18). This list is a compelling testament to the leadership roles that theme members play in the international research communities in which they participate.
- There was effective follow-through on recommendations from the 2014 evaluation, including ones related to investigating research topics such as 3D printing, AR, health, and presence in VR; allowing "new" project teams to naturally evolve from "old" ones; and condoning some overlap between teams and topics that might not fit a team's stated directions exactly when it results in quality research.

Theme-Related Recommendations

We make the following overall recommendations related to this theme, summarizing those made in the previous pages:

- Consider the potential to explore additional research areas (or reinforce how they are being addressed now), including conversational user interfaces, crowd-powered user interfaces, user-centered security, interaction for wearables, audio interaction, and interaction issues related to cloud and distributed architectures and edge computing.

- Recognizing the exceptional quality and impact of the research being done in this theme, continue to be supportive of some overlap between teams and of some research topics that might not fit a team’s stated topic statement, as long as the teams produce high-quality output (as recommended by the 2014 evaluation panel).
- Consider taking further advantage of the many ways in which ML can be applied to HCI; for example, to make sense of the large amounts of data generated by mobile and wearable devices, as well as home sensors, and in a wide range of domains, including health and wellness.
- Consider what can be done to increase the ethnic diversity of teams to better reflect French society.

PROJECT ALICE

Primary Topics and Objectives

Twelve years after its creation, the ALICE project team is today recognized as a leading research group in geometry processing, with a distinctive expertise in meshing and its applications to numerical simulations. The team was characterized since the very beginning by a solid background in mathematics coupled with a constant attention to computational aspects, placing the team in a vantage position in the geometry processing field. Thanks to the brilliant leadership of its founder, Bruno Lévy, the ALICE team approached several problems related to meshing and its applications, mainly to rendering and hex-mesh generation, with original and innovative solutions contributing to concrete advances in the field. The topics addressed by the team evolved in recent years into two main streams of research: one targeting a dramatic scale change in meshing for numerical simulations, with computational physics as the application context (GRAPHYS), and one focusing on effective techniques for shape modeling to support the whole computer-aided fabrication pipeline with the creation of a new team, MFX, led by Sylvain Lefebvre.

The geometry processing theme covered the improvement of meshing strategies, with a focus on the production of hex-dominant volumetric tessellations with an increasing rate of hex cells in the mesh (from 72% to 98%). The fabrication theme covered topics related to the synthesis of finely structured material, capitalizing on the ALICE project expertise in texture synthesis and on its generalization to the creation of volumetric textures.

International Standing and Reputation in the Field

The ALICE team reached and maintained over the years an excellent positioning in the international scenario, as documented by its constant and rich scientific production. Their publication record is impressive and includes the best conferences and journals in the computer graphics community, while their high-quality collaborations indicate both international recognition of the team's expertise, and its capacity to collaborate at the national level with other Inria teams. Bruno Lévy and Sylvain Lefebvre have both attained international visibility, with active roles in scientific events and in scientific journals.

Major Achievements and Impact

The ALICE team achieved several outstanding results, the most notable being four ERC grants won by team members. Given the competitiveness of the ERC programme, this is definitely an impressive indicator of the relevance of the research topics addressed by the group and of the innovative potential of the results achieved.

Scientifically, the most prominent results in the evaluation period are related to the excellent publication record (12 ACM TOG papers, and 15 others in peer-reviewed high-quality journals in both graphics and applied mathematics).

The Impressive quality of the software produced over the years was demonstrated during the evaluation session. The attention to the development of software libraries incorporating research results is quite a distinctive feature of the ALICE team, and the large number of downloads of GRAPHITE, GEOGRAM, VORPALINE, and IceSL demonstrate the interest of the scientific community in the results achieved and their impact.

Industry Transfer and Partnership

The potential industrial impact of the research carried out by the ALICE team is extremely high. Regarding geometry processing, meshing will become increasingly important, due to the continuously expanding capabilities for carrying out computationally complex simulations: digitization today offers a plethora of challenges to develop simulation models for a wide range of physical phenomena, and it will be necessary to support this trend with robust discretization methods for the geometric domains. Regarding digital fabrication, the diffusion of additive manufacturing approaches opens up a full spectrum of potential applications. The research directions pursued by the MFX team seem really promising, especially for the development of software solutions that could support the personalization of products and goods of various kinds. Of particular interest is the work on the synthesis of highly complex volumetric textures, and the procedural language adopted to produce rather complex looking shapes. The research theme is highly relevant, both in the short term and mid term, and it is well complemented by the next challenges that the team will address, concerning the coupling of modeling for fabrication tools and shape optimization approaches, and the possibility to include graded material in the fabrication process.

The impact of the research theme is also demonstrated by the success of the ERC Proof of Concept ICEXL project. Typically, this kind of funding is given to develop high-quality scientific results obtained through ERC-funded projects into a commercially viable proposition, as the initial steps of pre-competitive development.

Training of Personnel

In the reporting period, the ALICE team supervised six PhD theses and one member achieved an HDR. The team also contributed a lot to teaching and high-level training, mostly at the Ecole des Mines Nancy, Ecole Nationale Supérieure de Géologie, and Telecom Paris.

Principal Strengths and Weaknesses

The major strengths of the ALICE team are its unique mix of deep mathematical knowledge, which enables the team to approach problems with the correct theoretical and formal settings, and its complete control over the full implementation pipeline, which enables the team to produce solutions of high impact to the scientific community.

In this last reporting period, the ALICE team also demonstrated an outstanding level of creativity, being able to anticipate trends and to propose novel and timely solutions.

Future Plans

The ALICE team reached its natural end, after 12 years of successful activities. As suggested in the previous evaluation report, the team has already prepared for the next phase, with the proposal of the new MFX team, and the computational physics group evolving into the GRAPHYS team.

The MFX team will continue to pursue digital fabrication, with a clear research programme structured around the main theme of tackling the synthesis of complex shapes with easy-to-use interactive tools. The GRAPHYS team actually started in response to the recommendation made in the previous evaluation report, challenging the group to further exploit its competence in handling large-scale geometric problems. Computational physics is a relatively new field of research, whose scientific interest is surely high, but whose innovation potential is still to be demonstrated.

Opportunities and Risks/Difficulties

Since ALICE is coming to its natural end, there are no specific opportunities to suggest, besides expressing a favorable opinion regarding the direction planned by the MFX and GRAPHYS teams.

The only risk to mention is the new position taken by the founder of the team, who is now director of the Inria Nancy-Grand Est research center. It will be important for the GRAPHYS team to identify a worthy new leader for these research topics.

Recommendations and Suggested Measures of Success

Not applicable

PROJECT AVIZ

Primary Topics and Objectives

Founded in 2007, the AVIZ team is situated at the forefront of the vibrant fields of data and information visualization and visual analytics. The major aim of the project is to advance scientific understanding by facilitating the interactive visual exploration and analysis of large and complex datasets, using approaches informed by fundamental insights from visual perception and cognition. Specific objectives include: (1) designing and implementing novel methods for the more effective visual representation of diverse types of information extracted from disparate sources of data; (2) fundamentally expanding the domain of data and information visualization to encompass a wider array of visual and haptic display devices that afford new possibilities and new challenges for the effective communication of task-relevant information; (3) architecting new data storage, information retrieval, and data processing frameworks to enable the interactive visual exploration and progressive analysis of massively large datasets that current visual analytics methods are unable to successfully handle; and (4) conducting basic research in cognitive and perceptual principles relevant to effective visual thinking and decision making.

International Standing and Reputation in the Field

The AVIZ team is widely recognized as a leading research group in the international visualization community. The outstanding reputation of the team is evidenced in multiple ways. One is through their exceptional publication record in the top journals and conferences in the fields of Visualization and HCI, including two Best Paper awards at *ACM CHI* and one at *ACM UIST*, as well as several Best Paper Honorable Mention awards at the *IEEE Information Visualization and Visual Analytics* (*VAST*) conferences. A comparative analysis of publication provenance among European institutions puts the AVIZ team in first and third place among the highest productivity contributors to the *IEEE Information Visualization* and *IEEE Visualization* conferences, respectively. Each of the AVIZ team's long-term senior personnel (J.-D. Fekete, P. Dragicevic, T. Isenberg, and P. Isenberg) appears among the top 20 most productive researchers (out of nearly 500 authors) at these conferences, with two appearing among the top five.

In addition, AVIZ researchers have been unusually active in leadership positions in the scientific community. Members of the AVIZ team are well-represented on the scientific program committees, award committees, steering committees, and editorial boards of the leading conferences and journals in the field. AVIZ team members have organized or co-organized numerous conference workshops on critical topics, from interactive data exploration, to novel evaluation methods and improved statistical communication, to data visualization on mobile devices, and have also been active in organizing multiple Dagstuhl seminars on emerging themes related to their research, including data physicalization and progressive data analysis. Over the past four years, AVIZ researchers have also been invited to give multiple invited talks including five keynote addresses. This extraordinary visibility in helping to define the future research agenda for their field as a whole is truly exceptional.

The AVIZ team's outstanding reputation in the international community is further evidenced by the number and quality of their collaborative partners. Over the past four years, the AVIZ team has pursued a great variety of international collaborations with researchers from over 30 different universities outside of France. These projects involved joint work with individuals and research groups at top universities in Austria, Canada, Denmark, England, Germany, Italy, Korea, the Netherlands, Norway, Spain, Switzerland and the USA, including institutions such as Stanford, Harvard, TU Wien, U Konstanz, UMD, NYU, and U Calgary. The number and quality of these partnerships is a strong indication of the high international regard for the AVIZ team's talents and activities.

Major Achievements and Impact

The AVIZ team has demonstrated outstanding research productivity over the past four years, evidenced by their 88 peer-reviewed journal and conference publications, seven edited books or book chapters, and seven technical reports. Over half (27) of their 47 journal papers were published in the premier publication venue for visualization research, the *IEEE Transactions on Visualization and Computer Graphics*; fourteen more appeared in journals widely recognized to be among the top five in the field. The team's major achievements can be grouped by category:

1. **Novel Visualization Techniques.** Over the past four years, AVIZ researchers have developed an impressive 20 new representational methods, providing support for the more effective visual understanding, analysis, and communication of data in diverse application domains, from bitcoin (e.g., visualizing financial activity on the bitcoin network and elucidating the transactional behavior of individual entities), to biology (e.g., illustrating white matter structures in the brain and enabling the multiscale visualization of DNA nanostructures), and from the digital humanities (e.g., facilitating the exploration and organization of art image collections and visualizing connections in a 17th century businesswoman's network) to medicine (e.g., enabling the occlusion-free visualization of blood flow while preserving the indication of vessel wall thickness, and stylizing surgical images to mitigate their negative affect); as well as developing new methods for the improved visual analysis and understanding of dynamic networks and hypergraphs, including the visualization of temporal evolution in data. This body of work not only demonstrates astounding creative productivity, but the developed methods clearly provide critical support to enable groundbreaking new scientific discoveries in multiple important application areas. In addition, the team has made valuable theoretical contributions through their surveys of illustrative methods and research efforts to categorize visualization techniques and formalize design spaces.
2. **New Contexts for Visualization.** In addition to exploring new representational methods for data visualization and visual analysis, as described above, the AVIZ team has also focused on exploring new *contexts* for visualization. These contexts include non-traditional displays: small devices, such as fitness trackers or smartwatches, which

present novel challenges for effective micro-visualization; large immersive systems, which present novel challenges and opportunities for direct/natural interaction with the data and display; and physical/tangible representations; as well as nontraditional situations for viewing and interaction: embedded and situated visualizations, in which the data is directly displayed in its pertinent context, such as to visualize noise levels in an office; and collaborative visualization, in which the interpersonal communication aspects must be well considered in addition to the data display requirements. Each of the research directions in this category is exceptionally innovative and important, and these efforts are representative of how the AVIZ team is helping to set the agenda for future research in the visualization field as a whole.

3. **Visual Analytics for Big Data.** Massively large datasets present complex, unique challenges to effective visual analysis, and the AVIZ team's visionary concept of progressive data analysis offers a fundamentally new approach to this problem. The idea of computing and presenting estimated responses to queries whose exact solution would require prohibitively disruptive latencies is groundbreaking. Because successfully programming progressive analysis algorithms is a difficult feat, the AVIZ team has been working on developing a robust software infrastructure to make the necessary functionality broadly accessible. This is an ongoing effort that will require significant further investment.
4. **Cognition and Decision Making.** The new progressive analysis capabilities being developed by the AVIZ team (described above) open new questions related to cognitive processing and incremental interpretation. Over this review period, the AVIZ team has made several significant contributions to empirical research in perception and cognition, including studies on visual judgments, cognitive biases, and decision making, which inform the design of more effective visual data representations. Beyond the specific insights provided, which are valuable in their own right, the AVIZ team's research in this area (as in others) is strongly impactful because it has raised awareness in the visualization community about the importance of going beyond low-level studies of information detectability and discrimination to a more fundamental examination of the understanding people derive from what they see.

In each of their four main research thrusts, the AVIZ team's work is particularly notable for its groundbreaking nature. Not only is the team making specific contributions to address particular needs in the end-user community (e.g., historians, scientists, medical researchers, and financial analysts) but even more importantly, their visionary efforts (e.g., in data physicalization, progressive analytics, micro-visualization, and visualization literacy) are opening up multiple exciting new directions for future research in their field as a whole.

Industry Transfer and Partnership

Although the AVIZ team has pursued collaborative research with partners from Google and Microsoft Research on several different projects, industry partnerships do not seem to have been a primary focus for the AVIZ team. However, this is not to say that there is any lack of a strong user base for the AVIZ team's results.

Over the past four years, the AVIZ team has developed four different visualization systems, which they have made freely available through Github under BSD, GPL, and CeCILL-B licenses, as well as a new JavaScript visualization library (Reorder.js) and a novel open-source hardware platform for tangible display and interaction. In accordance with the recommendations of the previous evaluation team, the AVIZ team has focused on distributing their novel software and hardware as open-source systems rather than relying on commercial partners, in order to achieve more widespread dissemination and utilization of their products. This choice is also a reflection of the inherent tension between research and development under conditions in which both student time and engineering support are limited.

Training of Personnel

The outstanding reputation of the AVIZ team is evident in the quality of the researchers they have trained. Over the past four years, the AVIZ team has graduated six PhD students, including two who won international honors for the quality and impact of their PhD theses: Samuel Huron, Sept 2015 (winner of the *2015 IEEE VGTC Visualization Pioneers Group Best Dissertation Award*) and Jeremy Boy, May 2015 (winner of the *2015 IEEE VGTC Visualization Pioneers Group Best Dissertation Honorable Mention*). Many recent PhD graduates from the AVIZ team are currently working as postdocs at top universities across Europe and North America, including one person who is now at Stanford; in addition, two recent PhD students and one recent postdoc have succeeded in acquiring faculty positions at strong universities in Paris and Canada. One of the few engineers formerly affiliated with the AVIZ team (2015) is currently studying for a PhD. The notable success that AVIZ team alumni have had in achieving highly desirable research-related positions after their time in the group is a strong testament to the high quality of the training they received.

AVIZ team members have also been active in organizing training activities for PhD students at venues such as visualization-focused doctoral colloquia and summer schools. Such training investment for the benefit of the broader visualization research community is laudable.

Finally, in what we believe should also be considered as training activities, AVIZ members have devoted a total of well over 200 hours over the past four years to teaching. Team members have taught multiple regular academic courses as well as short courses in computer graphics, information visualization, and visual analytics, at diverse institutions, both domestically and abroad. The AVIZ team's consistent investment in teaching reveals a strong dedication to the mission of training the next generation. Furthermore the breadth and quality of the international institutions served, including places such as Harvard, NYU Poly, U Granada (Spain), and U Dresden, speaks strongly to the high esteem in which the training talents of the AVIZ team members is held.

Principal Strengths and Weaknesses

The AVIZ team is comprised of world-renowned researchers who are making prolific contributions to research through groundbreaking work on important problems and inspiring new directions of scientific inquiry in their community.

The team's attention to fundamental principles in visualization design is a valuable complement to their efforts in developing new visualization techniques. Their big data visual analytics work, both present and future, is highly important, and the goal of developing a programming language that is inherently progressive is significant. Close collaboration with data and systems researchers will be needed. Likewise the taxonomy work, both present and future, is valuable in providing an intellectual framework—the design space—that can be used as a guide by visualization developers, as a basis for experiments comparing alternative designs, and as a basis for automatic generation, including Tableau-style "show me" capabilities.

Continued attention to coherence in the team's research efforts will be important going forward. At present, there are multiple synergies between the team's four major themes (e.g., novel devices motivating novel display methods, and progressive analysis opening up new questions related to cognition and decision making) but particularly with respect to the development of new visualization techniques, attention to a clear unifying focus remains crucial to ensuring fundamental, long-term impact.

Future Plans

The AVIZ team will be reaching the prescribed end of its 12-year lifecycle in 2019 and will need to reinvent itself. Given that AVIZ is one of the most highly respected groups contributing to the *IEEE VIS* conference and associated venues, we believe that it would be ideal to try to keep the core team together. They have worked in multiple areas (from data physicalization, to ML explanations, to progressive analytics) and are now getting into more fundamental cognitive modeling for insights and actions.

Moving forward, many of the team's emerging research thrusts, such as progressive data analysis and visualization, data physicalization, cognitive studies, and theoretical foundations are all really strong and deserve to be further pursued. Given the work with ML, a natural direction would be to use visualizations to increase ML understandability—visualizing why conclusions are reached, as a way to expose biases and increase confidence.

Taking cognition into account as part of decision making could be extended towards the larger goal of creating systems to understand and work with user intent. Natural Language Processing (NLP) can be valuable when applied towards this goal, and we note that Inria has an NLP group; collaboration with that group would be appropriate if that goal is pursued.

The research thrust with zooids—data physicalization with micro robots—is compelling in its creativity; it demands the attention of observers. The next step should be to find and experiment with compelling use cases (perhaps in education).

With regard to future development efforts on specific visualization methods designed by the team, the Bertinizer application is very nice and it's a pity that it hasn't been incorporated into bigger systems such as Microsoft Power BI or Tableau.

Opportunities and Risks/Difficulties

Progressive programming is a particular challenge not only for PhD students, but also for engineers and collaborating researchers. A substantial investment in personnel, including permanent professional engineers, might be required to ensure success for this important thrust.

Recommendations and Suggested Measures of Success

As the AVIZ team must soon be reborn, there is little opportunity for recommendations regarding the future, save that the strength of the team and the significance of its work should be recognized and built upon going forward.

PROJECT EX-SITU

Primary Topics and Objectives

As stated in their own report, “ExSitu explores the limits of interaction—how extreme users interact with technology in extreme situations.” This implies working with creative professionals, such as musicians, artists, and choreographers, and working in ways beyond standard desktop metaphors. Particular attention is paid towards post-WIMP interaction (also known as Natural User Interaction metaphors), and how it can be developed, deployed, and evaluated. In addition, the team believes that theoretical work is underdeveloped and underrecognized in HCI, and is striving to ground interaction techniques in a more foundational framework. This includes casting an appropriately critical eye towards previously published work, whether it was a thrust for replicating previous findings, to revisiting Fitts’s law, to examining (and correcting) the statistical basis for gesture elicitation studies.

International Standing and Reputation in the Field

EX-SITU continues to maintain its impressive international reputation, placing it among the top research labs worldwide. As mentioned in the previous report, Wendy Mackay (team leader) and Michel Beaudouin-Lafon are members of the CHI Academy, an honor bestowed by ACM SIGCHI to “individuals who have made substantial contributions to the field of human–computer interaction.”

Since “reinventing” themselves as EX-SITU, the team continues to have multiple papers each year in top venues receiving best paper and honorable mention awards. The team points out that while some of their work has been published at *CHI* and *UIST*, fundamental theoretical research can be somewhat difficult to publish in these venues because of their focus on strong, empirical evaluations. We applaud their focus on a bigger framework than the “least publishable unit” that can plague academic departments.

Major Achievements and Impact

In their report, they have divided up their achievements along four different axes of impact: Fundamentals of Interaction, Human–Computer Partnerships, Creativity, and Collaboration. We will adopt this same structure in analyzing their contributions.

- **Fundamentals of Interaction.** They seek a “unified theory of design, that is generative in nature”—something that both tries to bring together disparate theories of interaction as well as recommend techniques for approaching particular problems. For this work, they received Best Paper and Honorable Mention awards at *CHI 2017* and *CHI 2018,* respectively. Their “Webstrates” work has informed several later publications both within the group and by external researchers—receiving over 40 citations in two years—a sign that their work is making an important impact on the community.

- **Human–Computer Partnerships.** One project demonstrated at the evaluation meeting was CommandBoard, which embodies some of their philosophy on using ML to assist humans in accomplishing tasks, as opposed to trying to eliminate humans from the loop. This work extended their previous work on Octopocus by generalizing and allowing people to specify interactive gestures with which they were comfortable and familiar. One problem noted in this area is the difficulty of gaining access to increasingly closed systems, especially in the mobile phone space. Finding ways of working more closely with industry would be useful across the board.

- **Creativity.** Evaluation of creativity tools is notoriously difficult, but the team has strived for close collaborations with domain experts such as choreographers and designers, which has helped inform their design choices. The team notes the difficulty in this kind of evaluation, since time and accuracy measures mean little for these creative professionals. They also note the difficulty in creating robust systems for long-term evaluation. Still, their work has been recognized with honorable mention awards at CHI, reflecting the respect that it is accorded within the research community.

- **Collaboration.** Their work on collaboration has produced numerous papers at *CHI* and *UIST*, including a best paper award at *UIST* for the abovementioned work on Webstrates). Their work on collaboration on large displays helps lead the field.

Industry Transfer and Partnership

They have relatively little interaction with industry and while they focus on creative professionals, deeper ties with industry could benefit both them and industry partners. Such partnerships though, are notoriously difficult, but tighter relations with companies such as Adobe, Microsoft, Google, and Amazon—all of which have research areas devoted to creativity support—could be a fruitful area of investigation. It might also ameliorate a difficulty identified by team members: finding skilled programmers capable and willing to work on specific projects.

Training of Personnel

Based on their report, they have had a good track record of training students for doctoral, postdoctoral, faculty, and engineering positions.

Principal Strengths and Weaknesses

Of all the teams, EX-SITU was the most effective in framing a larger context for their work and setting up how each project fits into this framework. In particular, they state that their “long-term goal is to create a unified theory of interaction grounded in how people interact with the world.” While there was significant breadth in their offerings, they still managed to have a consistency of approaches/sensibility in each project by tying it to the theoretical framework they seek to develop.

As already mentioned, they have consistently done top-notch work gaining recognition from their peers in the form of honorable mention and best paper awards at premier venues. They have grounded their work by collaborating with creative professionals. This helps make their work engaging, real, and boundary pushing.

They have commented that they appreciate the commitment that Inria has to long-term agendas. Some thought that they might be able to benefit by expanding their definition of "extreme" people beyond creative individuals. While they include "extreme situations" in their purview, a variety of definitions of "extreme" can be beneficial—from assistive technologies for individuals with challenging needs, to experts in high-stress situations (e.g., disaster relief, medical experts, operating other machinery). These could help push in different directions, especially for evaluation, since creative professionals can often adapt to even the most awkward of user interfaces (e.g., see https://www.huffingtonpost.com/2013/07/12/etch-a-sketch-anniversary_n_3581395.html)

They have noted some difficulty in both acceptances in conventional conferences and expanding impact in directions other than academic publications. While pushing the boundaries of science through publication is of paramount importance, finding ways in which tools can be used by a broader audience, through either open source software or partnerships with companies to develop ideas into products, could benefit everyone.

Future Plans

They have identified the current industry trend toward exploring AI and ML as both an opportunity and a challenge. It is interesting to think about how to harness the capabilities of ML in effective UI frameworks and they already have a start in exploring this area with their work on Bayesian Information Gain. Other areas can be addressed include Human-in-the-Loop interfaces that combine the best of ML with effective interaction techniques, which is an important and intriguing direction that is getting a lot of attention in several communities right now. We hope this work can be expanded on in the future.

Opportunities and Risks/Difficulties

As many teams reflected, there is no easy way to turn their work into impact beyond the duration of the project (e.g., through engineering resources that would help harden code for use beyond the departure of its PhD student author). They are already exploring more ways beyond their successful publication record through education, workshops, spinoffs to other teams, and joint projects with other teams and academic institutions. Other ways that could be emphasized more include open-sourcing software and promoting its use by interested communities.This is closely related to trying to scale up impact beyond the publication venue. It would be great if others could use tools that are developed by the team.

Recommendations and Suggested Measures of Success

Given some of the above recommendations, perhaps engaging in closer industry partnerships could help drive additional success. In addition, continuing to expand the definition of “extreme” may be useful in embarking on new partnerships, formulating new metrics for success, and developing new applications for interaction techniques. Finally, finding new ways of incorporating ML into smooth human-in-the-loop interaction would be particularly exciting.

PROJECT GRAPHDECO

Primary Topics and Objectives

Computer graphics workflows have not changed dramatically since the infancy of the field. The process involves a series of tedious steps (modeling, texturing, animation, and rendering) that are time consuming, consume a lot of computational power, and require professional skills.

Attempts to simplify the tools for novices and, in particular, to make use of more intuitive sketch-based interfaces or cheap scanners have not been completely successful. The results that novice users can achieve are far from the desired quality.

The GRAPHDECO team proposes to leverage the new types of democratized hardware together with recent advances in computer vision and sketch-based modeling, as well as the huge amount of data available to everyone. The expectation is that better algorithms can compensate for the imperfections of inexpensive sensors. The quality of the images produced should improve while hiding the complexity from novice users, and improving the efficiency of professionals.

The project is organized along two main axes:

- Improving the shape-creation pipeline by explicitly taking into account that input devices are inaccurate.
- Making the best use of imprecise and heterogeneous data to produce the best images possible.

International Standing and Reputation in the Field

Over the evaluation period, the GRAPHDECO team has published 25 articles in international journals and 23 in international conferences. The level of the journals and conferences is excellent.

Both Drettakis and Bousseau are actively involved in the community: associate editor for major journals (amongst which are *IEEE Transactions on VIsualization and Computer Graphics* until 2015 and *ACM Transactions on Graphics*), members of committees for leading conferences such as *SIGGRAPH* and *Eurographics*, and reviewers for conferences and journals.

GRAPHDECO is definitively one of the top research groups in its field. This is confirmed by the collaborations that the team was able to establish with prestigious groups such as those of Alexei Efros (UC Berkeley), Karan Singh (U Toronto), and Frédo Durand (MIT), further noting that Durand spent one year with the team as a visiting professor.

Considering that the team has only two permanent members, this is outstanding productivity.

Major Achievements and Impact

The GRAPHDECO team has contributed to two major areas:

- **Sketching and vectorization.** The team has been focusing on how to improve design exploration. In particular, they have concentrated on how to convert imperfect 2D sketches to usable 3D shapes, which is still a major open problem in the industry. GRAPHDECO proposed novel algorithms to infer 3D shapes from characteristic lines, while better preserving the designer's intentions. They also proposed using a deep-learning approach to identify candidate shapes from a database matching a specific sketch. Since deep-learning algorithms require a large training database, they proposed to use synthetic drawing based on their non-photorealistic rendering (NPR) software to build a database much larger than what designers could have created.

- **Image-based rendering (IBR).** The team has proposed a new algorithm to dramatically improve the end-result for specific situations: building with repetitions, reflective known objects such as cars, thin structures or varying lighting conditions. Their expertise in deep learning was an important contributor to this success and allowed the team to design new methods that produce significantly better results than previous ones.

The most visible impact of the project has been the large number of papers published by the team. Their introduction of deep-learning techniques in both areas has been extremely productive.

Several software libraries were developed by the team for line rendering and vectorization, sketch-based modeling, and IBR. They are mostly used internally to compare to other known algorithms or serve as a platform for demonstrations.

Industry Transfer and Partnership

GRAPHDECO has collaborated with numerous international research institutions: UC Berkeley, U British Columbia, and U Toronto. The collaboration with UC Berkeley is the most formal one and resulted in an international project called CRISP. The other collaborations are less formal, but contributed to their large number of publications—a good many of these articles include authors from other institutions. The academic collaborations of GRAPHDECO are of very good quality and most certainly contribute to the productivity of the team.

The industrial relationships are still in infancy. Technicolor and Adobe have contributed to the project funding and published joint papers. However, this has not yet resulted in specific software or IP transfer.

Optis is currently co-funding a CIFRE PhD thesis. This work has already produced a significant advance in capturing spatially varying bidirectional reflectance functions from a single image, by leveraging ML. This work was presented at SIGGRAPH, and is further being disseminated through the distribution of data and code.

Also to be noted, a substantial amount of time was spent on trying to form a startup to leverage their IBR software and expertise. While this helped improve the quality of the software developed by the team and the presentations validated the potential of the GRAPHDECO technology, this startup project is currently on hold until someone in the team is available to formally create this startup. We hope that this investment of time and effort will be leveraged in the next evaluation period.

Training of Personnel

The team is currently composed of 12 people, with two permanent researchers. This number has been stable over the evaluation period. There are six PhD students at the moment, which is a relatively high number for two researchers.

During the evaluation period, four students completed their PhDs and have moved to industry. Six postdocs and two professors have been invited.

Principal Strengths and Weaknesses

Strengths:

- The team is extremely productive, which is demonstrated by both the number of papers published during the evaluation period and the quality of the conferences and journals that accepted those papers. In addition, GRAPHDECO was able to create good academic connections with internationally respected research institutes.
- They built deep-learning expertise that gives them the potential to create breakthroughs in both IBR and sketching. A more traditional approach may result in only small incremental improvements.
- The solid rendering expertise and in-house software platform are assets for creating the large amount of input data needed for their deep-learning algorithms.
- The research is very much driven by real industry problems with good potential for integration into or complementing commercial products.

Weaknesses:

- The team is small with only two permanent members, and seems to be spread thin for the amount of research they plan to do in the next period.
- The emphasis of software development is on internal usage more than wider availability.
- The connection with industry seems a bit weak. The work with Optis should be continued and further strengthened. The team could also test their sketching algorithms better if they had access to a larger input database for sketches and 3D models.

Finally, we note a point that is neither a real strength or weakness, but an observation: Their two main areas (sketching and IBR) are a bit disconnected. Even though new ideas can come from discussion between the team members, it looks like the project is assembled from the competencies and interests of its members more than from a clear long-term goal. The same point has also been noted in other projects during the evaluation and deciding whether this is desired or not should be discussed at a higher level, noting the recommendation made by the 2014 evaluation panel to be wary of “stifling the freedom of productive researchers to pursue topics of interest.”

Future Plans

The team is already engaged in two projects funded by ERC grants for the next four years, which will be their primary focus:

1. D^3 (Drawing interpretation for 3D Design) is an initiative to improve the ideation phase of creative design. The goal is to better interpret 2D sketches to find or reconstruct 3D shapes. The team wants to understand how traditional professional drawing techniques are used to convey the idea of a 3D shape, so they can use this knowledge to guide reconstruction. The research will focus on creating a solid database to represent those techniques, find ways to determine which specific techniques were used in a particular sketch, and finally provide early feedback while sketching about the feasibility of the design.

2. FUNGRAPH aims at providing an entire framework to improve image rendering in the case of inaccurate input data. Three research themes have been identified:

    - Creating a unified framework to embed several algorithms and expose the degree of uncertainty in the result in order to best combine these results.
    - Exploiting the uncertainty of the input data during the content creation phase to further improve the rendering algorithms.
    - Finally, producing realistic rendered images that can be used to train deep-learning algorithms for the determination of uncertainties.

Opportunities and Risks/Difficulties

The largest risk of the project seems to be the team size, in particular the small number of permanent members. This might have been aggravated by the large time investment of Drettakis and the engineer on the PicPlay project, which is unfortunately on hold at the moment.

The team has a well-defined roadmap and funding for the next four years. This should guarantee a level of stability for the project.

The expertise in ML is a very good addition to the team competencies and could be a differentiator in how to revisit IBR and sketching.

Recommendations and Suggested Measures of Success

The external collaborations and the visits of faculty such as Durand helped to increase the visibility of the team and resulted in the publication of several papers. This should be continued and encouraged during the next period. This can also act as a stopgap measure until the team can grow.

The investment in PicPlay should be leveraged. A decision should be made rapidly to either identify a project leader to create a startup and assemble a team, or to open-source the software.

The team should be encouraged to create stronger links with industry. Companies such as Google and Microsoft have created large image databases of digital photographs. Having access to a fraction of these could dramatically improve the deep-learning results. Similarly, specialized 3D companies such as Autodesk and Dassault Systèmes could provide interesting input sketched by professional designers. These companies would be good candidates for technology transfer.

PROJECT HYBRID

Primary Topics and Objectives

The HYBRID team develops and investigates novel 3D interaction methods and devices for virtual environments, using both body and brain inputs. They address three challenges:

- Interaction paradigms adapted to 3D content
- Modeling and simulation of complex virtual environments, and
- Immersive sensory feedback and rendering algorithms

Their goal is to reconnect the body and the mind in VR, improving immersion (presence) and interaction (performance). To this end, the team develops 3D user interfaces, focusing on haptics and Brain–Computer Interfaces (BCI).

International Standing and Reputation in the Field

The HYBRID research team has a very strong standing in the international research field of VR, augmented reality (AR), mixed reality (MR), and 3D user interaction. Since 2014, the team of seven professors and numerous very talented young researchers has produced 33 journal publications and 61 peer-reviewed conference papers, many of them in premier venues with very low acceptance rates. The researchers are highly visible internationally, serving as general chairs and program chairs of top conferences such as *IEEE VR*, *IEEE ISMAR* (*International Symposium on Mixed and Augmented Reality*), *ACM SIGGRAPH*, and *Eurographics*. They have also served frequently on the program committees of these and other conferences and are members of the editorial boards of leading journals (*IEEE Transactions on Visualization and Computer Graphics*, *MIT Presence*, *IEEE Computer Graphics and Applications*, and *Frontiers*). Furthermore, the team has received several very prestigious awards (best paper, best dissertation honorable mention). In line with this very high research reputation, the team has also been very successful in acquiring external funds for both European and national projects.

Major Achievements and Impact

The HYBRID team has produced very interesting and important results along a number of different research directions:

- The team has conducted very strong, convincing experiments concerning users' sense of embodiment in VR applications with respect to issues of priority/lag, consistency/jumps and exclusivity/wrong motion prediction. The six-finger experiment and the cross-gender shadow experiment lead in very promising directions.
- The research on novel haptic devices investigates combinations of many different aspects of tactile, tangible, and proprioceptive feedback, both in mobile and stationary settings (with fixed robot arms). The selected combinations of variants are creative and have high potential towards laying the groundwork for the next generation of haptic interfaces.

- The team has created a very useful research platform, Immersia (#FIVE and #SEVEN), upon which they have been able to systematically build and investigate a large number of complex studies of 3D interaction in 3D environments, related to various application topics such as cultural heritage.
- Embarking on the new research direction of multi-modal AR, the team has started investigating whether/how users' interactive experiences differ between applications in AR and VR. They have made a quite remarkable finding that haptic feedback is perceived to be softer in AR settings than in VR settings.
- The HYBRID team has also started research activities in the challenging area of Brain–Computer Interfaces (BCI). They have established a sound system/software foundation and have produced first findings as to how well humans can interact via this exciting modality without focusing merely on the interface itself. The selected application areas (medicine, athletics) are highly suitable.

Industry Transfer and Partnership

With its research platforms #FIVE and #SEVEN and with the OpenVIBE software package, the HYBRID team has started producing powerful applications in various domains. On this basis, the team is in a good position for collaborating with industry and for open distribution of their platforms. The Mensia Startup, collaborations with the b<>com Institute, Polymorph and MBA, and a number of bilateral collaborations for PhD theses all lead in this direction. Their considerable number of patents lays a solid foundation for technology transfer to industry. The team might want to consider strong ties to the automotive industry (e.g., for driver assistance systems and e-mobility) and to manufacturing companies ("Industry 4.0").

Training of Personnel

The team has grown well in the last evaluation period. Some extensions were made in very relevant areas and have resulted in a significant increase in productivity—yet, this extension was not well balanced between Inria and the associated institutions: even though the team has nominally grown over the past four years, the Inria staff itself has decreased from nine to eight. To pick up, enhance, and maintain the strong momentum of the team, more engineers are needed to build up and run the apparatus conducting the experiments. At the same time, the number of female team members should be increased to improve the gender balance. Furthermore, the novel BCI theme needs to be extended with a junior researcher (CR).

14 doctoral dissertations and habilitations have been completed, which is a very good outcome.

Principal Strengths and Weaknesses

Strengths:

- Very active and very technically competent team.
- Very forward-looking research directions.

- Very powerful hardware and software infrastructure to build and investigate experimental environments for 3D multi-modal UI research quickly and flexibly (Immersia).

Weaknesses:

- The team wants to improve immersion and interaction. They need to define how to measure/quantify the improvement.
- The team might still be too small. (See comments above on training of personnel).
- The relative lack of motivation of the team for sound integration into their current techniques portfolio could represent a shortfall in the HYBRID multi-modal approach for AR/MR.
- Building and maintaining infrastructure requires much system-level work. In principle, this requires a professional product development and marketing team such that the full benefits can be gained from distributing the system beyond internal use. There is a thin line between providing unique, novel flexibility and aligning with novel developments in the fast moving commercial software market. It is hard to remain at the cutting edge of system development at a research lab (fewer personnel in comparison to efforts in industry).

Opportunities and Risks/Difficulties

Opportunities:

- VR/AR/VR, 3DUI, and BCI are currently very hot topics with increasing visibility both in academia and in commercial enterprises. The field is at a critical turning point. Some research evidence has been generated in recent decades; yet much still needs to be explored before commercial success is secured for a wide base of applications.
- Much technical expertise is required for solid investigations/enhancements of the state of the art; Inria/HYBRID has this expertise and is thus in a prime position.
- Thus far, the field of experts is small. Consequently, there is high potential for interesting research across a wide range of topics.
- Industry (Google, Facebook, et al.) are willing to invest much into academic investigations in this area. With such support, very forward-looking scientific experiments can be explored.
- The HYBRID team has a well-defined roadmap regarding valuable next research steps.

Risks/Difficulties:

- Based on the tremendous funds available in industry, development and research may progress very fast in some research areas. It is hard to compete with such massive commercial impetus in an academic lab.
- Thus, research directions must be selected wisely to be outside the to-be-expected trodden path of commercial activity: Don’t do whatever industry will do for you.

- The HYBRID team's positioning regarding open source or other collaborative strategy for their #FIVE and #SEVEN software suite must be clarified to obtain the industrial impact they are targeting for effective dissemination.

Future Plans

The HYBRID team is very aware of the rapidly changing times, due to increasing commercial impact. They respond to this drastic change by extending their research along the following dimensions:

- From VR to MR.
- Tackling important perceptual issues.
- Addressing "hot topics" brought to VR mass-market: "avatars" and "immersive haptics."
- Deepening "hybridization" and "physiological VR."
- Towards promising applications and transfer opportunities.

These research directions are well chosen, since they go beyond the first-level, direct next steps in improving technical aspects of emerging immersive technologies. Rather, these topics aim at underlying human issues and at cross-functional, hybrid use of technology.

Recommendations and Suggested Measures of Success

The fields of 3D interaction (VR/MR/AR/...) are expanding fast in many directions. Mixing and matching many emerging novel technologies in ever-new combinations is being pursued in many research labs and companies. It is important for a small group such as the HYBRID team to set clear priorities and select a few strong research themes as their prominent research directions, thereby ensuring a unique research profile.

The HYBRID team is already heading in this direction. It might be worthwhile to sharpen their unique selling points even more (the introductory page https://team.inria.fr/hybrid/ is rather generic) and to produce more specific expectations/hypotheses, such as a few specific technical settings that will be explored. These hypotheses can then define measures of success.

PROJECT ILDA

Primary Topics and Objectives

The primary objectives addressed by the ILDA team relate to what they refer to as the *web-of-data*¸ for which large amounts of data are made available to machines as semi-structured data. Specifically, ILDA is performing research that is based around the observation that interactive systems will play a key role in a large proportion of data-driven activities. With growing amounts of data, users will require suitable interactive tools to understand and manipulate their data. The ILDA team is approaching this problem from three different directions:

- **Semantics-driven Data Manipulation.** The goal of this axis is to rethink how users explore and interact with large datasets, while taking advantage of newly available technologies that can support the interlinking of semi-structured data.
- **Generalised Multi-scale Navigation.** The goal of this second axis of research is to develop new methods to display large amounts of interconnected data that can support efficient navigation, especially in distributed environments.
- **Novel Forms of Input for Groups and Individuals.** The goal of this third axis is to design interactive systems that can improve group awareness. This will be done by capturing distributed data-centric tasks, studying them in particular situations, and designing interaction techniques for individuals and groups of users that take advantage of novel input technologies.

These three subgoals are being developed with two separate contexts of use in mind. First, the researchers are looking at *mission-critical contexts of use*, in which subject matter experts may need to construct mental models and make informed decisions under time pressure. This includes scenarios such as emergency response and management, and critical infrastructure operations, such as public transportation systems, communications and power distribution networks, or the operation of large scientific instruments such as particle accelerators and astronomical observatories. The second context is *scientific data analysis,* including domains such as astronomy, molecular biology, particle physics, and neuroanatomy.

International Standing and Reputation in the Field

As a newer team, ILDA may not yet have the same level of international reputation as some of the other teams at Inria. ILDA is a spin-off the former IN-SITU team, and is not yet as well known as IN-SITU was. However, its team members, and in particular its research scientists and faculty members, are amongst the top researchers in the field of visualization and HCI, and all have an impressive international reputation. While they do not have a prestigious senior researcher on their team (their HCI research careers all begin in the early 2000s), this is no doubt an all-star team of researchers, and we would expect their reputation, both individually, and as a group, will only grow further in the coming years.

The team leader, Emmanuel Pietriga, has published extensively in the top-tier conferences and journals related to his field, including the *ACM CHI* conference (*CHI*), *IEEE Transactions on Visualization and Computer Graphics* (*TVCG*), and *ACM Transactions on Computer–Human Interaction* (*TOCHI*). Many of these papers have won awards at their respective venues. Caroline Appert is also a rising star in the HCI community, having published extensively in *CHI* and *TVCG*. She has also won multiple best paper and honorable mention awards. In 2017, she served as the Papers Co-Chair of *CHI*. Anastasia Bezerianos is also amongst the top researchers in the field of interactive visualization, perhaps best known for her work on visualization and interaction using large displays. She recently had three papers accepted to *IEEE InfoVis 2018*, a very impressive accomplishment. Olivier Chapuis has also been actively publishing in the top HCI research conferences, and is very well known in the international research community for his development of new input and interaction techniques.

Major Achievements and Impact

The ILDA team has been responsible for a number of major achievements:

Scientific Dissemination: In the last four years, the team has published an impressive number of articles in top research conferences and journals in the field, including ten *CHI* papers, eight *TVCG* articles, and two *TOCHI* articles.

New Data Manipulation and Navigation Techniques: The team has introduced a number of new data manipulation techniques that leverage the semantics and structure of the data. This includes their work on browsing linked data catalogs (LODAtlas) and the interactive exploration of multiple ontology alignments (Alignment Cubes). They have also produced a number of complementary techniques for navigating large datasets, such as their work on navigating plans for before-and-after satellite images, and on navigating large-scale data related to crisis management (MapMuxing).

Novel Input Techniques: The team has also developed a number of new input and interaction techniques. Most notably, their work on TouchTokens offers a new way to prototype and implement low-cost tangible interfaces.

Industry Transfer and Partnership

In addition to conducting and publishing its research in collaboration with a number of academic partners, the ILDA team is also collaborating with industry: Their work on exploring a design space of animated edge textures for attribute encoding in multivariate graphs has been done in collaboration with Microsoft Research. Besides interactions with other Inria teams (e.g., AVIZ), and universities and research organizations in Paris (e.g., Telecom ParisTech), the team has academic partnerships with colleagues at the Open University, Northwestern University, and Monash University, amongst others.

The ILDA team has begun to make an impressive number of their software contributions publically available, which could eventually lead to industry transfer, such as their ZVTM toolkit, TouchToken API, Smarties Client, LoadAtlas Portal, MapMosaic System, and Baia Framework. Additionally, they have a longstanding collaboration with the ALMA radio observatory (Atacama Large Millimeter/submillimeter Array), related to the design and development of novel user interfaces for the observatory control room. This has led to new collaborations with the CTA (Cherenkov Telescope) and LSST (Large Synoptic Survey Telescope).

Training of Personnel

ILDA currently has six PhD students and no postdocs, and over the evaluation period, four team members earned PhD degrees. The training that these members have received is positively impacting their careers, as they have all continued in their research. One former postdoc is now a researcher at Masaryk University and another is now a postdoc at the Federal University of Rio Grande do Sul, Brazil. The graduated PhD students hold postdocs at Monash University, ENAC, and the University of Sussex, and one is now an Assistant Professor at City University of Hong Kong.

All permanent team members are teaching extensively in the areas of HCI and Data Visualization, mostly at Université Paris-Sud and affiliated schools such as PolyTech Paris-Sud and IUT. In addition, Anastasia Bezerianos has been the co-head and head of the HCI Masters program at Université Paris-Sud and EIT Digital from 2015 to 2018 and Caroline Appert is also Vice President of Data, Knowledge, Learning and Interaction at STIC.

Principal Strengths and Weaknesses

Without doubt, the team’s principal strength is the quality of research they are doing in the area of intersection between HCI and large datasets. The team is made up of leading experts in these areas, and is publishing high quality research in the top tier international conferences and journals. Also impressive is the extent of software systems that the team has developed and released. This form of contribution is encouraged as the team continues and it strengthens the potential impact the team can have on the research community. The team is also doing an impressive job training personnel, with its recent graduates moving on to research positions at other labs, and one PhD student now an Assistant Professor.

The main weakness that this team has is defining a coherent theme that brings together all of its research areas. While the team’s presentations tried to present their work as defined by three axes, the relevance of these axes to one another, and in particular the third (novel forms of input), were not clear. Specifically, the work on TouchTokens may be the most impressive from a research standpoint. It was a pleasure to see this work presented in detail, but the work simply doesn’t fit within the other themes that the team is addressing.

One solution is to ensure that research on novel forms of input ties in better to the applications being explored in the other two axes, however, this may weaken the research being done. A longer term solution may be to think of new organization structures that would allow this research to have a better fit.

As another example, the project members presented their work on Before-and-After Satellite Images as an example of “Generalized multi-scale navigation.” This research was quite interesting, but it was not clear how it was an example of multi-scale navigation. Categorizing it this way felt forced. Taken together, the team may think of stepping back and understanding how a cohesive story can be told about the research they are doing, that better involves each of their team members.

Another minor weakness of the team is in its ability to maintain collaborations with other Inria teams, while still creating enough separation to have ownership over specific research topics. Given its similarity in research themes to the AVIZ and EX-SITU projects, it is understandable that this may be a difficult task.

Future Plans

ILDA has completed its first four-year term. Looking forward, the team has a number of plans for the next four to eight years of the expected duration of the project team:

- **Focus on the research direction of generalizing multi-scale navigation.** The team’s current research is focused on interaction and visualization for classic information spaces. They would like to now generalize the concept of multi-scale navigation to “highly-heterogeneous, distributed and interlinked datasets whose contents are discovered on the fly.”
- **Gradually shift to semantics-driven data manipulation.** While the current work is focused on visualization and navigation, the team will begin to look at techniques to support selection, extraction, merging, and aggregation of data for the purpose of sensemaking and analysis.
- **Better integration of interaction techniques and co-located collaborative work.** As noted above, and within the project report, there is currently a divide within the work being done on their third research axis. The team plans to look at the potential of using tangibles not only as tools to interact with the system, but also as sharing mechanisms between co-located users.
- **Develop work that demonstrates all three axes.** The team intends to maintain an emphasis on their three axes of research, but hopes to develop research projects that can serve as demonstrations of all three axes simultaneously, uniting them into a single coherent vision.

Opportunities and Risks/Difficulties

As described above, the research team has a number of areas of focus that they intend to look at over the next four to eight years, which all represent substantial opportunities. Another major opportunity that they have is to increase the collaborations and interactions with other research teams, such as AVIZ.

One risk that the team must consider is the overlap in its research agenda with the other Inria teams. This can reduce the team’s impact and visibility. The team has already identified a weakness in its limited visibility in the web community; however, there may be a concern that even in the HCI community their group's substantial contributions may be overshadowed by other groups that may have more established team members.

A final risk is the dependency the team has on obtaining access to large datasets in the domains in which they are working. While the team has been doing a good job so far at establishing strategic collaborations and partnerships, access to enabling data could become more challenging, especially with current privacy concerns and new policies in place such as the General Data Protection Regulation (GDPR).

Recommendations and Suggested Measures of Success

We recommend that the leaders of ILDA continue to build the team, recruit top PhD students and postdocs, publish their work at leading venues, and maintain high visibility. We also encourage ILDA to refine the description of their research axes so they are more encompassing and coherent, and differentiate their work from others at Inria, while at the same time improving cross-team collaborations. Research related to visualization and interaction with large-scale data is of extreme importance, and a potential area of research that the team may consider is to incorporate findings and methods from ML into their work, so that the data-driven tasks they are exploring can be, to some extent, machine-driven. The team should also continue to leverage their collaborations with external researchers and institutions, and deploy their software as SDKs and toolkits for use by other researchers.

PROJECT IMAGINE

An evaluation of project IMAGINE must address two key points. First, the team experienced major personnel changes during the last four-year period: Marie-Paule Cani and Damien Rohmer left the team, Rémi Ronfard took the role of team leader, Frederic Devernay joined and left, and Melina Skouras joined recently. Second, the project is now ending its eight-year period and is therefore evolving into a new project proposal called ANIMA, in which all current team members are planning to stay. Because of this, most of the evaluation of the previous four years will address the old project and its team members, and most points regarding future research will address the new proposal and its relation to the current team members.

Primary Topics and Objectives

The goal of the IMAGINE project was to develop a new generation of models, algorithms, and interactive environments for the interactive creation of animated 3D content and its communication through virtual cinematography. After the previous evaluation report four years ago, the project focused on three main axes: shape design, motion design, and narrative design. As the previous report commented, the diversity of subjects covered by this team was a little too wide. Nevertheless, the size of the team at that stage and the diversity of fields of the team members (geometric modeling, graphics, vision, anatomy, and cinematography) did cover the three main axes.

The previous report suggested separating the project into two more focused fields. Instead, the team decided to focus on a smaller number of application areas and incorporate narrative design into each of them: modeling, animation, and cinematography. This is also the theme of the new proposal ANIMA, which adds “story-driven” to all three application areas (“axes”).

As the team members seem to work well together, and the team had downsized considerably from 36 to 20 members, we believe this solution seems to fit well and provides opportunities to continue collaborations while utilizing the strengths of all team members.

International Standing and Reputation in the Field

Marie-Paule Cani, Rémi Ronfard, Stefanie Hahmann, and other members of the team have very strong international reputations in their fields.

Marie-Paule Cani (former team head) was the Technical Papers Chair for *SIGGRAPH 2017* and an IPC member of *SMI 2015*, *Expressive 2015*, *MIG 2015*, and *Eurographics 2016*.

Rémi Ronfard (current team head) co-organized several workshops including three editions of the *Eurographics Workshop on Intelligent Cinematography and Editing* (*WICED)* in 2015–2017. He gave a keynote talk at the *ICCV 2018 Workshop on Computer Vision and Audiovisual Media* (*CVAM*).

Stefanie Hahmann co-organized several international conferences including the *Dagstuhl seminar on Geometric Modeling* in 2014 and the *SIAM Conference on Geometric Design* in 2017. She co-chaired the *ACM Symposium on Solid and Physical Modeling* (*SPM*) in 2016–2018 and is an associate editor of *Computer Aided Design* (Elsevier) and of *Computers & Graphics* (Elsevier).

Jean-Claude Leon has been an associate editor of *Computer Aided Design* and on the IPC of *SPM* 2015–2018.

These research scientists and other team members often present in international conferences and participate in international journal reviewing. The team produced numerous papers and collaborated with many top researchers in the fields of computer graphics, visualization, and computer vision.

Major Achievements and Impact

The publication yield of the team is impressive with around 40 journal publications, 40 conference publications, and 20 PhD theses.

Most notable regarding the first axis is the line of publications around modeling developable surfaces for design and production of, for example, shoes, bags, and clothes (e.g.,"Sketching Folds: Developable Surfaces from Non-Planar Silhouettes," *TOG*, *SIGGRAPH Asia 2015*, and "Patterns from Photograph: Reverse-Engineering Developable Products," *Computers & Graphics 2017*). These works illustrate deep mathematical knowledge motivated by the real needs of designers.

For the second axis, the works on sketching line of action and animation (e.g., "The line of action: an intuitive interface for expressive character posing," *SIGGRAPH 2013*, and "Space-time sketching of character animation," *SIGGRAPH 2015*) were influential because they bridged the gap between artistic theories and novel user interfaces—designing highly expressive and intuitive tools.

Along the third axis, the collaboration with Olivier Palombi on anatomical studies is an ongoing multidisciplinary effort that is unique and utilizes the strengths of both teams (e.g., "Anatomical augmented reality with 3D commodity tracking and image-space alignment," *Computers & Graphics*, 2017).

Lastly, the effort to integrate cinematographic knowledge in graphics is inspiring and pushing this rather new field forward (e.g. "Continuity editing for 3D animation," *AAAI 2015,* and "Automatic Focus+Context Split Screen Video Generation," *Eurographics 2017*).

Industry Transfer and Partnership

Most of the industrial impact of this team came from collaborations with industry on real-world problems. Several commercial companies funded PhD dissertations, resulting in direct knowledge transfer. Many of the team's alumni joined industry companies, resulting in implicit knowledge transfer. The team filed three patent applications, was awarded a patent for an earlier application, and distributed several software and tools for public use.

Training of Personnel

A yield of 20 PhD dissertations over four years is impressive. The team members also participate in teaching regularly and give lectures and talks in both France and international venues.

Principal Strengths and Weaknesses

The major strength of this team is undoubtedly its interdisciplinary nature. The combination of members' backgrounds has encouraged the creation of projects that are imaginative and inspiring. The motivation for the research problems the team is tackling often comes from real professionals from diverse fields, such as designers, movie/game producers, and educators. The team then uses the strengths of its members in mathematics and computer science to develop solutions that are effective and useful.

However, such diversity can also become a weakness if the projects that are chosen diverge too much, and each team member concentrates on their own separate research without coordinating towards a joint effort. For some of the work presented by the team, the link to the main theme seems a little contrived. Another possible weakness is the smaller size, as discussed below.

Future Plans

The new proposal for the ANIMA team suggests concentrating on three main axes (modeling, animation, and cinematography) that fit the strengths of the team members, and adding "story-driven" to these axes as a common theme. The key challenge is to build interactive narrative environments in which the "user is the director." A key component in all application areas seems to be reverse engineering from movies: shapes, animation, and cinematography. Therefore, a more data-driven approach is being adopted.

Opportunities and Risks/Difficulties

The new "story-driven" theme and narrative expressions present a key opportunity to impact the field: This is a novel approach and builds upon high-level semantic understanding, which is still a challenge. Nevertheless, such a theme seems to work well for animation and cinematography, a little less for modeling. For example, it is not clear what is meant by "reverse engineering shapes from movies."

That the team has shrunk in size and key members have left poses a possible risk. It would be difficult (if at all desired) to return back to the large team size. It is obvious that the number of publications and PhD students cannot be maintained, but such downsizing should also be handled with care. For example, that only one team member now has an appointment as a professor can make it more difficult to attract and recruit good PhD students. Another potential risk is that interdisciplinary research carried out by the team can sometimes be hard to publish, as it spans multiple fields.

It was not always obvious who the target audience is for the environments and tools that the team creates. Is it novices (thus democratizing creative expression) or professionals? There is a large difference in the way a tool should be designed and evaluated if targeted to non-professionals rather than experts.

Recommendations and Suggested Measures of Success

We believe, considering also the interdisciplinary nature of the team's research, that the team size should not be reduced further, and should probably even grow. The new team member Mélina Skouras is a very good fit to the team, with a strong background in math, physics, and design. Her fabrication background seems a little lost in the new theme and the team should also consider utilizing this strength.

That the new theme relies heavily on data and data-driven methods requires strengthening the team with experts in ML or similar fields. It is obvious that the design and graphics fields are moving towards utilizing these algorithms and methods.

PROJECT MANAO

Primary Topics and Objectives

The primary focus of MANAO is finding ways to bridge the gap between real and virtual. They approach this in a clever way. First they establish four main areas of research: Computer-Generated Imagery (CGI), instrumentation, optics, and perception. Then they build their research projects around combinations of these.

For example, their research into Digital Optical Systems is a combination of CGI, instrumentation, and optics. Their material appearance research combines CGI, optics, and perception. Their Visual Accessibility research combines CGI, instrumentation, and perception. Finally, their material fabrication research combines all four.

Their focus within the field of CGI itself is in appearance manipulation, level of detail, enhanced shape depiction, cache-friendly sampling, remeshing, elastic deformation, expressive rendering, procedural detail editing, surface reconstruction from particles, and light transport. Most of their work in optics focuses on the Wedge camera, freeform lenses, spherical displays and spatial AR.

They are particularly interested in understanding the interactions between light, shape, and materials—in particular how shape and light interrelate, how light and materials interrelate, and how materials and shape interrelate. This ties into their work on creating ways to design physical/visual effects, which touches on 3D displays, free-form lenses, and the nanostructure of materials.

International Standing and Reputation in the Field

They have a great publication record: 26 publications in 2012–2014, and 35 publications in 2015–2018. These were in many top publication venues, including *ACM Transactions on Graphics*, *IEEE Transactions on Visualization and Computer Graphics*, *Computer Graphics Forum*, *Optics Express*, *Journal of Visualization*, and *DisplayWeek*.

Major Achievements and Impact

Much of their positive impact on the field has been through their widely used software libraries and applications.

One of these is the *Eigen* library, which supports a wide range of linear algebra, matrix, vector, TensorFlow and numerical solver capabilities. Because of its comprehensiveness and generality, Eigen is applicable to many different application areas, and it is widely used in the geometry processing community.

Another is the *Patate* library, which implements a suite of CGI techniques that enable researchers to more quickly turn research results into ready-to-use solutions. It is open source, available to anyone under the MPL license.

Their *ALTA* library, which focuses on support for material modeling, provides a wide variety of Bidirectional Reflectance Distribution Function (BRDF) analysis tools. These tools allow captured BRDF data to be fit to various mathematical models.

Their *HDRSee* application supports high dynamic range and low dynamic range imaging and display and tone mapping. It is implemented as a set of OpenGL GLSL programs, which makes it compatible with a wide variety of Graphics Processing Unit (GPU) platforms. One great thing is that it makes it easy for developers to incorporate their own tone mapping solutions as plugins, which are then run in GPU hardware.

Their *Elasticity Skinning* software supports realistic surface deformations.

Their *Radiance Scaling* technique allows details to be enhanced in objects with shallow relief structures, such as carved stones. This technique has attracted wide interest in the archaeological community.

They also have an impressive amount of active outreach to the public via various exhibitions and forums. These include Mini-forum 3D, Fête de la Science, outreach to high school students, the Senate showroom, and participation in the FACTS exhibition.

In particular, we were very impressed by the way they are able to parlay the unique opportunities afforded by the use of the Wedge camera to enter into new application areas, such as measurement, and then analysis and modeling, of hard-to-reach visual targets.

Industry Transfer and Partnership

They collaborate extensively, maintaining both academic and industry partnerships. For optical research, they work with U Cambridge/Imagine Optic, and DIOTA. For materials research, they collaborate with TU Delft, Edge Hill U, U. Giessen, Unity, and NTT. For CGI, they collaborate with IRIT, Thermo Fisher Scientific, and Technicolor. Foundry (http://www.foundry.com) purchased from them and now sells a plugin embodying the MANAO Elasticity Skinning work for use in the company's Modo 3D-modeling system.

They appear to have rich and diversified industry funding.

Training of Personnel

Their principal researchers, Barla, Bénard, Guennebaud, Granier, Ihrke, Pacanowski, and Reuter are mentoring their PhD students, who have included Zubiaga, Restrepo, Mignard-Debise, Dövencioglu, and van Hassen. They are also developing the IOGS site in Bordeaux.

Principal Strengths and Weaknesses

One of their key strengths is that they have four different interconnected areas of research expertise upon which to draw under a common vision. This affords them great flexibility in how they combine these areas, as hardware and software continue to evolve.

Another key strength is their strong interaction with both other academic research groups and partners in industry.

On the other hand, one potential weakness is that the very breadth of their research agenda can make it difficult to create a truly organic connection between the disparate parts of their work. Choosing a strong unifying project might be helpful, perhaps one that focuses on interaction in AR/MR environments (since that is a direction that relates to all of their core strengths).

Future Plans

Their stated future plans include projects in analysis of rendering for perception, modeling/acquisition of appearance at nano/meso scales, 3D character animation/deformation, display/MR/visualization, and freeform optics/lighting design. These seem to be reasonable areas for them to focus on.

Opportunities and Risks/Difficulties

They have a coherent set of principles, so that the different aspects of their research agenda fit together in multiple ways.

Recommendations and Suggested Measures of Success

This team is doing extremely well in its current path and has a very good handle on things. We encourage them to continue exploring ways that the different parts of their research program can fit together. With the advent of ever more practical and high quality hardware support for wearable MR, that seems like a natural direction for them.

PROJECT MAVERICK

Primary Topics and Objectives

The MAVERICK team conducts research to create efficient and effective image synthesis methods. Their work is driven by focusing on what makes an image useful. Based on understanding image usefulness in different contexts, they develop new data representations, new ways to convert data to images, and new ways to evaluate the results.

As in the previous evaluation period, the team studies image synthesis in the context of four problem areas:

- *Computer visualization.* Synthesizing images from data to provide insights.
- *Expressive rendering*. Synthesizing images based on artistic intent.
- *Illumination simulation*. Synthesizing images that accurately simulate natural images.
- *Complex scenes*. Synthesizing images from large numbers of primitives.

These four problem areas each produce new insights into mathematical techniques, user interactions, and evaluation methods that are shared across the projects.

International Standing and Reputation in the Field

The MAVERICK team is led by senior researchers who are in the top tier of international research in graphics and visualization, for both their past and current work. In particular, Georges-Pierre Bonneau is a leader in the visualization community, Joëlle Thollot in non-photorealistic rendering, Nicolas Holzschuch and Cyril Soler in light transport for graphics rendering, and Fabrice Neyret in the rendering of natural phenomena. Romain Vergne is somewhat more junior, but has recently received significant recognition for his application of insights into human perception to creating and editing images. While the project name “MAVERICK” doesn’t have significant “brand” recognition outside of Inria, Bonneau, Thollot, Holzschuch, Soler, Neyret and Vergne have received a great deal of attention for their work in various combinations over the past four years.

Major Achievements and Impact

During the review period, project members made many contributions in each of the four problem areas, including the following major results:

- *Computer visualization.* The project members significantly advanced their work on tools that allow users to gain insight into scalar fields through topological analysis. In addition to continuing work on computing Morse–Smale complexes, the team developed a new algorithm for computing contour trees for tracking the topology of higher-order scalar fields.

- *Expressive rendering.* Project members were responsible for innovations on two fronts. First, they expanded the area of texture synthesis to the development of a technique for defining vector textures in a manner that is targeted to professional artists, rather than casual users. Second, they developed a method to edit image appearance based on the concept of perceptual image flow.

- *Illumination simulation.* The team continued work on efficient methods for light transport in participating media. Working with the MANAO team, the MAVERICK team was responsible for a breakthrough in reflectance modeling that addressed an issue observed more than a decade ago in measurements of common materials. A new reflectance model was developed that combines geometric optics and diffraction effects. A practical model that increases the gamut of reflectance effects in this way had not been produced in over 20 years.

- *Complex scenes.* The team continued work on managing complex scenes and filtering for accelerated rendering. Most impressive has been the work in texturing, and in procedural textures of arbitrary extent in real time based on moment-preserving blending.

Industry Transfer and Partnership

The team has strong partnerships with top research groups around the world.

The work is transferred to industry via publication and software. Team members work with industry—most notably Fabrice Neyret's extended visit with Weta Digital, a major player in the computer effects industry. The team also maintains connections with other key companies in the graphics space: Disney, Unity, and NVIDIA. In addition, the team's work is transferred through students entering industrial positions after their work with the team.

Training of Personnel

The team has a fine record of graduating PhD students and training postdocs. Five PhD students have gone on to industry, and two to postdocs. Both postdocs from the group have gone on to faculty positions.

The team members do a great deal of teaching, furthering their impact on training the next generation of computing professionals.

Principal Strengths and Weaknesses

The strengths of the project are the senior team members, and the diverse problem areas that have been chosen to generate new ideas that can be shared across the team. The team has an excellent collaborative spirit.

A weakness, due perhaps to funding and/or recruiting issues in today's economic climate, is the lack of engineers to support the development of software. Putting new algorithms and methods into a robust, practical form is essential for computing research to have rapid and high impact. With the complex results that are obtained, and with their dependence on previous work and code frameworks, simply making available the initial code that students develop as proof of concept is not adequate for effective dissemination.

Future Plans

The team has clearly set out future goals for each of the four problem areas. They have documented well how these goals have evolved from the work performed during the review period and have defined the continued connections between the individual efforts:

- *Computer visualization.* The team will focus on visualization of tensor fields. While tensors have previously been considered in the visualization field in the area of medicine, the team will push this area forward by interacting with atmospheric and material scientists. The team has already identified the opportunity to interact with members working on complex scenes as part of this effort.

- *Expressive rendering.* The team will focus on appearance design. This encompasses editing, stylization, and procedural textures. This work can connect with the effort in illumination simulation in specifying reflectance models, the computer visualization effort in stylization, and the complex scenes effort in generating textures of arbitrary extent.

- *Illumination simulation.* The team will build on their recent success in developing a new reflectance model to construct models for more complex materials such as fabrics and dry pigment powders. As noted, the development of systems for editing reflectance models is closely related to appearance editing in expressive rendering.

- *Complex scenes.* A major thrust will be the further development of procedural texturing, to widen the gamut of textures that can be produced and working with members addressing expressive rendering to provide intuitive designer control. An additional effort will be initiated in animating natural phenomena in support of the computer visualization work with atmospheric sciences.

Opportunities and Risks/Difficulties

The recent growth in three areas represent both opportunities and risks for the team's planned work: ML, GPUs, and VR/AR hardware.

ML has become a part of nearly all computing research. Other groups have applied ML to areas that the MAVERICK team is studying, notably design tools and illumination modeling (e.g., noise reduction techniques). Rather than seeking ML techniques that attempt to automate design or ignore existing physical models, the MAVERICK team has had great success focusing on the human aspect of design and models developed in the physical sciences. However, the team needs to continue tracking work in ML to identify the aspects of design and modeling that can be effectively enhanced with this new technology.

GPUs continue to drive the graphics industry, and the group has ties with NVIDIA, which leads in this technology. The introduction of the Turing architecture for hardware-accelerated ray tracing will have an impact on algorithms for illumination simulation, and the team needs to account for this in its work on light transport.

In developing an understanding of what makes a useful image, the group has conducted perceptual experiments. The perception of an image depends on the type of display used. The team needs to take into account hardware displays, especially novel VR and AR technology, as well as software controls, in designing intuitive user interfaces.

Recommendations and Suggested Measures of Success

The team has outlined excellent plans for their research, built on their insights from the past and their opportunities for collaboration. We do not recommend any significant changes in these plans.

We recommend that the team continue to disseminate their results in the form of open-source software. The team should also consider how they might participate in the open-source effort recently announced by the Academy of Motion Picture Arts and Sciences for the animation and special effects industries: the Academy Software Foundation (https://www.aswf.io/).

In view of the opportunities and risks just discussed, we recommend that the team devote time to considering how advances in ML, GPUs, and VR/AR hardware impact each of their major efforts.

With regard to measures of success, in addition to traditional publication in computer science venues, publication in the areas of the teams' collaborators (e.g., atmospheric and material sciences) should also be considered as measures of success.

PROJECT MIMETIC

Primary Topics and Objectives

The MIMETIC team focuses on analysis, modeling, and simulation of human motion. The main applications are related to biomechanics, sports science, virtual and drone cinematography, and virtual characters for entertainment.

The theoretical and technological problems tackled by MIMETIC researchers are difficult and interesting. Analysing human motion and simulating moving characters with high fidelity (up to the level of individual muscle activations) requires combining a vast array of complex techniques, ranging from inertial motion capture to high-performance biomechanical solvers.

The team joins multiple subjects together in a unique loop designed to model, capture, and virtually reproduce real human movement. They combine diverse areas in a novel way: motion analysis, activity recognition, muscle simulation, ergonomics, and sports science are explored through a unified and coherent narrative.

International Standing and Reputation in the Field

With more than 100 publications in journals and conferences, the impact and reputation of MIMETIC is clear. Most of the 12 professors and assistant professors are involved in many academic associations and conferences, including *Motion in Games, Computer Animation and Virtual Worlds, Computer Animation & Social Agents*, and *IEEE VR*.

During the evaluation period, team members participated in various events directed towards the public, in particular related to the interesting and fun aspects of sports science and virtual humans. MIMETIC as a brand might not be recognized internationally yet, but many of the team members enjoy significant strong reputations in their fields.

Major Achievements and Impact

The MIMETIC team's multidisciplinary position enables its researchers to study motion analysis and synthesis in unique ways. Here we highlight works that particularly attract our attention:

- We are impressed with the contributions in muscle quasi-static solvers that can quickly estimate detailed muscle activations from skeleton kinematics. Papers such as "The MusIC method," "Uncertainty propagation in multibody human model dynamics," and "Dealing with modularity of multibody models" are significant contributions.
- We enjoy papers that focus on a hard and specific motion such as "Low-dimensional motor control representations in throwing motions" and "Motion control via muscle synergies: Applications to throwing."

- We believe physics-based character animation is one of the most exciting subjects that MIMETIC explores, with papers such as "Dynamically balanced and plausible trajectory planning for human-like characters." One specific 2016 review paper, "Muscle-based control for character animation," was particularly useful to many practitioners. We trust that more work in this area would be interesting and impactful.

- Significant contributions related to action recognition, analysis, and retargeting include "Normalized distance matrices for human motion retargeting," "HIF3D: Handwriting-inspired features for 3D skeleton-based action recognition," "Curvilinear displacement based approach for online 3D action detection," "Automatic evaluation of sports motion," "Time-series averaging using constrained dynamic time warping with tolerance," and "Normalized Euclidean distance matrices for human motion retargeting." One of the most useful insights gained in this domain is that the representation used to describe movement does not have to be local or even global joint angles or positions, but can instead be expanded, depending on the task, to more adequate representation spaces such as sets of surface-to-surface distances.

- Contributions in motion reconstruction from noisy signals are impressive, with work such as "Filtered pose graph for efficient kinect pose reconstruction." Applications in ergonomics make this particularly interesting, with papers such as "Inverse dynamics based on occlusion-resistant Kinect data: Is it usable for ergonomics?"

- MIMETIC contributes a very large body of work to the biomechanics community, with deep and detailed studies of the incredibly intricate behavior of muscles and bones during human motion. With a refreshing focus on sports training, ergonomics, and health, the team can have real impact.

- A significant focus of the team is on applications in VR, such as sports training. This offers collaboration opportunities with sports and health academic groups, as well as professional sports organizations such as football teams.

- Kinematic character animation is tackled in papers such as "Perceptual effect of shoulder motion on crowd animation." We believe more work in this area would be needed to put MIMETIC at the leading edge of the virtual human community. The new Inria Project Labs AVATAR project, coordinated by MIMETIC, will likely inject renewed interest in this subject.

- MIMETIC contributes interesting work in virtual and drone cinematography, with papers such as "Intuitive and efficient camera control with the toric space."

- The team also studies pedestrian behavior, and measures it using VR apparatus.

Industry Transfer and Partnership

Several startups and technology transfers have emerged from work done by and with MIMETIC. The company *Moovency* was created based on Pierre Plantard's work on identifying and correcting unreliable joint poses reconstructed by a Kinect. The *SolidFrame* tool was transferred to *SolidAnim*, a company that used it in the previsualization phase of the movie *2.0,* the most expensive Indian film to date. Finally, the project BRDT is a successful transfer of technology for processing inertial data for medical and sports application.

It would be interesting to see more animation synthesis techniques developed within MIMETIC convert into startups. This happened before with *Golaem* for crowd animation, a great success in the movie middleware industry. It would be fantastic if this were to happen again with new revolutionary animation techniques.

Training of Personnel

The team's size went from 30 to 25, for various reasons. Julien Pettré left for Rainbow, and Ludovic Hoyet did not get contracts until 2017 to hire students and engineers in Inria. MIMETIC trained several PhDs, and they found good positions in academia and industry.

Principal Strengths and Weaknesses

The principal strength of MIMETIC is its raw talent and its focus on hard problems. The installations for motion capture are top notch, and they can use them in many contexts and with many different collaborating groups.

One weakness could be related to the small size of the group that focuses on virtual humans in game-like applications.

Future Plans

As detailed in the part of their report on future plans, the MIMETIC team wishes to hire more personnel in the virtual character area. We also believe that MIMETIC would benefit from gradually moving towards the real problems game developers struggle with when they try to believably populate their virtual environments. See, for example, the recent feat in virtual world authenticity that was achieved by Rockstar Games in *Red Dead Redemption 2* (e.g., https://www.theguardian.com/games/2018/oct/24/get-real-behind-the-scenes-of-red-dead-redemption-2-the-most-realistic-video-game-ever-made).

MIMETIC could get more involved by studying the paradigms that are currently used to control the non-player characters in modern games, and figure out ways to improve them in theoretically sensible ways. While it may make no sense to try to compete directly with large game and game-engine companies, we strongly believe that there is room for everyone to participate in this rapidly expanding field.

Opportunities and Risks/Difficulties

In movies and video games, animation programmers specialised in physics-based human animation are beginning to acknowledge the need for realistic muscle simulations and accurate biomechanical modeling. It is not enough to trust the crude approximations of PD control or simple motor constraints anymore. With the new animation-generation techniques based on reinforcement learning, precise measurements of comfort, muscle preference, and energy consumption are essential to define adequate long-term rewards for a character. Also, we do not want simulated ragdolls to be used only for dying or falling down stairs anymore. We want ragdolls that can be controlled by any motion-capture sequence, generalize intelligently from it, and behave realistically in their world.

The last years have seen astonishing breakthroughs in human-movement capture, simulation, and control. See, for example,

- *Deep Learning of Biomimetic Sensorimotor Control for Biomechanical Human Animation (http://web.cs.ucla.edu/~nakada),*
- *Learning Symmetric and Low-Energy Locomotion https://dl.acm.org/citation.cfm?id=3201397*
- *Interactive Character Animation by Learning Multi-Objective Control (http://mrl.snu.ac.kr/research/ProjectMultiObjectiveControl/index.htm),*
- *Learning Acrobatics by Watching YouTube (https://bair.berkeley.edu/blog/2018/10/09/sfv/)*.

Virtually all new approaches to animation synthesis use flexible hierarchical function approximators. Most methods also directly benefit from the exhaustingly rapid progress currently being achieved by reinforcement learning researchers. Despite annoying media over-hype and speculative irrationality, neural networks (or similar structures) are here to stay— with matrices and integrators, they now sit comfortably in the basic toolkit of modern computer scientists and engineers. Today, no computer vision work happens without data-learned function approximation. The same thing is happening to animation synthesis and robotics. There is no better time to jump in than right now.

Recommendations and Suggested Measures of Success

The multidisciplinary nature of MIMETIC (muscle simulation for serious biomechanics, motion capture and VR for fun entertainment) has the potential to put the team at the leading edge of a new and exciting science: data/physics-based animation synthesis. Closing the loop by combining biomechanical simulations, motion capture, and motion generation in game-like settings is a very exciting promise.

In conclusion, we recommend continuing as planned, possibly with a renewed focus on accurate virtual human simulation in analysis or game-like contexts. Can they solidify criteria for testing and measuring goodness? When embedding an avatar in VR, how good is good enough? How can they measure biofidelity? What about perceptual plausibility?

We recommend considering the possibility of using modern ML and reinforcement learning techniques for animation synthesis. This could include working with other teams using learning. Initiatives in ergonomics, sports science, virtual and drone cinematography, training, health, VR avatars, and other subjects tackled by MIMETIC should be enthusiastically continued. MIMETIC is well positioned to make a durable impact in the scientific fields to which it contributes. Regardless of the details of the applications, the ultimate goal is an important scientific pursuit: achieving a precise understanding of how the parts of our bodies behave and move through space.

PROJECT MINT

Primary Topics and Objectives

The MINT team, led by Laurent Grisoni, was originally created from members of IN-SITU in 2009 and then split into the MJOLNIR project team and a continuing MINT project team in 2014. The project team then ended in December 2017. The scientific objectives for this evaluation period focused on tactile-interaction hardware, understanding gestural interaction, and new forms of MR and proxemic interactions.

A distinguishing feature of the MINT team is its interdisciplinary nature, bridging researchers in both Computer Science and Electrical Engineering. This has enabled the team to develop and build novel interaction hardware devices, which drive the core of the team's research. By leveraging their hardware, the team has been able to open new avenues of research, such as their studies with human-factors experts to understand human tactile abilities.

The team also emphasizes putting their technology out in the world for use by the public. They have collaborated with startups to commercialize their devices and have built installations for museums that demonstrate the practicality of the technology that they have developed.

International Standing and Reputation in the Field

The team has established a strong international reputation through its publications in selective conferences and journals, primarily in the haptics domain (e.g., *World Haptics*, *Eurohaptics*, and *IEEE Transactions on Haptics*). Prizes were also received for best demo at *ACM ISS*, best work-in-progress paper at *Eurohaptics 2016* and a best paper award at *ICMT*. Two patents and five art–science events show the ability of MINT to turn their research into usable technologies that can be consumed by industry and the general public.

MINT maintains a large number of productive international collaborations with prominent researchers, including Luke Dahl (U Virginia, USA), Joaquim Jorge (INESC-ID, Portugal), Ed Lank (U Waterloo, Canada), Marie-Ange Bueno (U de Haute-Alsace, France), Mickael Adams (U Birmingham, United Kingdom), Andre Moureaux (U catholique de Louvain, Belgium), and Masaya Takasaki (Saitama U, Japan).

Contributions through several European projects, including Prototouch and VR4REHAB, position MINT as an important research team in gestural interaction and MR interaction.

Major Achievements and Impact

In this evaluation cycle, the team has been particularly productive in technology transfer, producing two startups (Hap2U and GoTouchVR) in haptics and MR. Hap2U has commercialized the XploreTouch vibrotactile tablet, which is now available as a developer kit and received a CES Innovation Award at the *2017 Consumer Electronics Show* (*CES*), the leading trade show in this broad field. Commercialization of the XploreTouch tablet has allowed the project team to conduct fundamental research into haptic perception, leading to three papers at major conferences.

Recent work in the team's new directions on proxemic interaction and MR interaction have been productive. This work has attracted international collaborators from Canada and Portugal, and has led to four papers (two in each area) at top conferences.

The team also continues to participate in art–science projects that make their technology accessible to members of the general public at venues such as the Lille central library and a local natural history museum. Five projects were successfully completed in this evaluation cycle.

Industry Transfer and Partnership

Two patents were filed during the evaluation period, and one of those plus two previous patents were licensed. The project team works closely with two startups, GoTouchVR and Hap2U.

Training of Personnel

During the evaluation period, six students obtained their PhDs. While this is one less than during the last evaluation period, the number of faculty decreased substantially because the teams were split. Therefore, thesis productivity seems to be higher in the present evaluation cycle than in the previous cycle.

Principal Strengths and Weaknesses

Strengths:

- The team's interdisciplinary nature enables it to do unique research in haptics that would not be possible from researchers in computer science or electrical engineering alone.
- The team is strong at system building, which leads to compelling demos and art–science projects. This strength is no doubt responsible for their success in transferring technology to startup companies.
- The team has built a number of successful international and regional collaborations that extend the breadth of their research (e.g., in human factors for tactile interaction).

Weaknesses:

- The team's work sometimes seems technology-driven instead of problem-driven. While it does seem valuable to pursue general solutions to haptic problems, we wonder if it might be more productive to focus on a small number of specific problems for which haptic technology can make a crucial difference.

- The team seems to spend a lot of time on engineering compared to conducting fundamental research. Working more in depth on a smaller number of systems may lead to more research productivity.

- The project team no longer has a member that is a full-time Inria employee, which limits its ability to move forward.

Future Plans

The project team has officially stopped as of December 2017, but the individual members continue to work together on research projects. Planned work areas include simulation of complex tactile sensations (e.g., the feeling of different kinds of cloth), next-generation tactile-feedback devices, and projected-agency interaction.

Opportunities and Risks/Difficulties

MR and VR are growing areas, and the project team is smart to have already begun work in these domains. We believe that the interdisciplinary nature of the team is well suited to making an impact in MR and VR, for which haptic interaction will be increasingly important.

Recommendations and Suggested Measures of Success

The team faces logistical difficulties, in part due to their unique interdisciplinary nature. Most notably, computer science and electrical engineering are in different funding organizations within CNRS, which creates hurdles for obtaining joint funding for members of the team. We believe interdisciplinary research work is important to the health of the computing field and recommend that Inria, CNRS, and other relevant organizations work together to remove the barriers that would prevent it.

The team also seems to have some difficulty identifying the best application areas for their technology to have impact. If possible, hiring a product manager, or simply consulting with a business expert on a semi-regular basis might help the team focus better on the most fruitful opportunities for their technology.

PROJECT POTIOC

Primary Topics and Objectives

The primary topics addressed by the POTIOC team are MR applications for education, inclusive design, MOOCs for learners with ADHD, BCI, and neuroergonomics. The objective is to continue developing innovative user experiences and tools using different types of technologies. The rationale for adopting MR as a unifying theme for these disparate areas is that it can be used for designing a diversity of new user experiences, especially in education, in comparison with physical or digital interfaces alone. While MR research has been ongoing for decades, it is interesting to see how this group is developing new application areas, given that the technology has matured, and is now far more capable and affordable than in the past. With this in mind, the team has shifted their research from developing prototypes that are tested in the lab to moving their prototypes into real classroom settings and evaluating their impact on learning. This development is to be commended, as many challenges must be overcome in the process.

The name POTIOC stands for “popular interaction,” which relates to the use of new interfaces, technologies, and HCI techniques by the general public. This is a broad topic, allowing for a diversity of research projects to be pursued. However, this also makes it difficult to see commonalities in objectives across the research themes being addressed; for example, it is difficult to see what connects the research agendas in BCI, MOOCs, 3D interaction, spatial AR, and neuroergonomics. Certainly, by themselves, they are important and exciting areas of research but underlying links between the topics and themes are lacking, other than at a high level. The application areas include education, mindfulness, and spatial navigation—all of which involve quite different challenges and research questions. A new area that has potential to make these links is inclusive design in education, whose projects include working with visually impaired people and developing MOOCs for people with cognitive disabilities. This strand of research looks promising, but it is not clear as to whether it is the domain per se or the development of technology that is the driving force.

International Standing and Reputation in the Field

The group is now six years old, with a young researcher as its leader, Martin Hachet. This appointment at the start was admirable and very much in the vein of promoting promising young researchers to be future leaders. Hachet continues to be internationally known for his work on 2D and 3D interaction and environments, having a very good h-index for someone of his standing. Since leading the group, Hachet has been invited to be on various conference steering and program committees (e.g., *IEEE 3DUI*) as well as general chair for *Conférence francophone sur l’Interaction Homme-Machine 2013* (*IHM*). Fabien Lotte, another young member of the team, is internationally known in BCI, as evidenced by many highly cited papers.

Major Achievements and Impact

POTIOC's publication record continues to be at a very high level, indicating the significance of the team's contributions in their respective fields. A highlight of the team's achievements is the HOBIT project (Hybrid Optical Bench for Innovative Teaching), in which a novel MR system for teaching optics was developed and evaluated in schools. This work was published in the top tier conference *ACM CHI 2017,* where it received a best paper award. This is a major achievement. Another paper, published in *ACM CHI 2018,* was based on their research investigating collaborative learning of spatial concepts and skills for sighted and visually impaired students.

Industry Transfer and Partnership

The applied nature of their research puts the project in good stead for industry transfer and partnership with other areas of research and application domains. The startup RealityTech has spun out from their research and concentrates on using projector-based spatial AR, which does not require users to wear headsets. This is led by a former member of POTIOC, Jeremy Laviole. Moving the research increasingly into the domain of education has enabled members of the team to work more closely with teachers in real school settings. The team also successfully transferred their Toucheo project to a company, with a commercial product based on the work now available and a patent pending.

Training of Personnel

The group remains small but has a good track record in training its personnel. Several PhD students have graduated in the last two years and three new PhD students have joined. The students and postdocs who have moved on all have good positions in industry and academia.

Principal Strengths and Weaknesses

Strengths

- Several of the projects presented and described have a high level of creativity, innovation, and potential for impact (e.g., HOBIT and PAPART).
- The project team is open to new research challenges and opportunities.
- The move to working in inclusive design is timely and addresses real educational applications and accessibility.
- The team's work continues to be published in top-quality conference venues and was recognised through a best paper award.
- The team is interdisciplinary in nature, with researchers from technical and social science backgrounds.

- The team is very good at working with partners in other areas as they explore the potential of MR user interfaces, including artists, musicians, jugglers, and teachers.

Weaknesses

- The eclectic set of projects makes it difficult to sum up what the group is about. Similar to what was noted in the last review, the team can be described as working on a set of projects that are only loosely related, rather than taking a coherent approach to answering a small set of research questions.
- The term “popular interaction” is not commonly used in HCI and it is difficult to see what is meant by “popular” across the portfolio of projects.
- A new full member of the team left after three years for personal reasons, leaving a gap, so the team continues to be small compared to others.

Future Plans

The team is still relatively young and small, even though the project is now into its sixth year. Their future plans are to remain open to new ideas and to support research “finding a place” for everyone. A number of promising collaborations have been established, forging links with the University of Waterloo, with the aim of promoting curiosity in learning. There are also plans to work more with the LOKI and HYBRID teams, including co-supervision of a PhD student. These seem incremental developments. It would be good if some of the future research could focus on explicating the bigger picture about advances in user interaction—in particular, developing new understandings from the insights gained from augmenting learning and engagement.

Opportunities and Risks/Difficulties

The team is still small for one that is six years old.

The three axes could continue to go their separate ways, which is a risk, since it is not clear what the common principles are underlying the research themes in BCI, neuroergonomics, AR in education, and inclusive design.

Developing AR to be robust enough to be applied in experimental and real world settings takes significant engineering effort and the team seem under-resourced to make this truly happen.

Recommendations and Suggested Measures of Success

One idea is to consider rethinking their research theme in terms of “multi-sensory interaction,” rather than sticking to their original concept of “popular interaction,” especially now that some of their work is beginning to move in the direction of combining different input and outputs. This would be more in line with some of the exciting new themes in interaction design and HCI at large. We also recommend that they start to consolidate the various research strands on how new interfaces can enhance and augment learning in real world settings. It would be great if they can begin to develop an overarching theoretical approach explaining how different technologies are able to focus the mind and augment cognitive processes—this could potentially be a major contribution to the field.

PROJECT TITANE

Primary Topics and Objectives

The TITANE team was formed in 2014 and is located in the Sophia Antipolis–Méditerranée Inria Research Center. Their primary topic is the geometric modeling and processing of complex scenes from physical measurements. This overall objective is conceptually split by the team into three main steps: *Analysis* (object classification and structure extraction), *Reconstruction* (with a specific focus on man-made objects within indoor and urban datasets to provide robust shape reconstruction even with imperfect data), and *Approximation* (ranging from levels of details for geometry compression, to polygonal approximation of images through mesh simplification, mesh generation, and inter-surface mapping.).

The team objective has evolved into the adoption of “inverse procedural modeling” to recover the structure of complex scenes from the raw measurement of data. This reinforces one of the project team positions of providing semantic urban modeling with the tight integration since 2015 of ML techniques during the analysis and classification of images.

International Standing and Reputation in the Field

Pierre Alliez (team leader), Florent Lafarge, and Yuliya Tarabalka have made substantial contributions to the fields of international journals such as Computer Graphics, Vision and Remote Sensing.

Despite the limited number of staff, the TITANE team has an overall excellent academic standing, with a good number of publications in highly ranked venues. These have received three best paper awards (*EUROGRAPHICS Symposium on Geometry Processing 2016*, *IEEE International 2015*, *ISPRS Journal of Photogrammetry and Remote Sensing 2014*).

Most of the results of the team are available in the world-renowned suite of open source software CGAL (Computational Geometry Algorithms Library), on whose editorial board Pierre Alliez serves.

Major Achievements and Impact

The main scientific results achieved by the team over the last period are:

- A novel shape-detection algorithm to extract planar objects from 3D data at different levels of abstraction, published in *CVPR 2018*, that can be integrated into existing structural formalisms such as the CityGML Levels Of Details (the open standardised data model for 3D models of cities and landscapes).

  In collaboration with the spin-off Geometry Factory (see below) and former PhD student

Simon Giraudot, this has been implemented as a new CGAL component for the classification of 3D point sets.

- A semantic classification approach of aerial and satellite images with deep-learning architecture. The generalization of this semantic labeling method has been published in *IEEE IGARSS 2017,* coupled with an aerial-image–labeling benchmark dataset with different training and test cities in the US and Austria.

- A multimodal image-alignment technique to align and update aerial and satellite maps with recurrent neural network architecture, published in *ECCV 2018*.

- A Voronoi-based partitioning of images to preserve geometric shapes within the image partitions, published in *ECCV 2016*. This partitioning can be used in a geometry-aware classification of urban scenes, preserving facade and rooftop edges, as well as building corners.

- A kinetic approach for partitioning images into polygons, with output partitions that contain fewer polygons and better capture geometric structures than those delivered by classic partitioning methods, published in *CVPR 2018*. This technique makes it possible to generate a fast object contouring in 2D, which can be applied to synthesize massive satellite datasets. Based on the same approach but with more complex generalization, the team has started to develop a spatial partitioning of 3D data that could be applied to 3D surface reconstruction.

- A novel method to obtain classification maps in vector format, based upon decimation and optimization of dense initial meshes from aerial and satellite images, published in *IEEE IGARSS 2018*. Another approach has been done with a deep-learning network to predict vertices of four-sided polygons.

- “Curved optimal Delaunay triangulation,” a mathematical approach to refine curved meshes for high precision and topology optimization of 3D models, published at *SIGGRAPH 2018*.

- “Inter-surface mapping via optimal mass transport,” based on a mathematical optimal transport formulation to establish a meaningful correspondence mapping between two input surfaces, published at *SIGGRAPH 2017.*

Industry Transfer and Partnership

TITANE has an impressive track record of collaboration with industry. The team obtained five CIFRE PhD theses (LuxCarta, CSTB, Airbus, Dorea, Dassault Systèmes) and four patents with Google regarding advanced progressive geometry compression. Other research collaborations have been established with IGN, CNES, ACRI group, Thales, and Innodura.

TITANE has several partnerships with other Inria teams, such as AROMATH and DATASHAPE (both in the *Algorithmics, Computer Algebra and Cryptology* theme), and GRAPHDECO, MANAO, and TAU (in the *Optimization, Machine Learning and Statistical Methods* theme). They also have many ties with other academic partners including California Institute of Technology (USA), RWTH Aachen University (Germany), ENPC, and INSA Lyon.

Industry transfer is widely supported with the development of the open-source CGAL library, whose commercial license has been handled by the team spin-off company Geometry Factory since 2003. Part of the revenues are reinvested for the maintenance of the library. Geometry Factory is also developing new software packages and listening to the needs of the market, which can be reported back to the team to factorize existing components or decide the development of new concepts.

Training of Personnel

During the evaluation period, six students obtained their PhD.

Three research scientists (one senior and two junior) are training and advising PhD students, and at the time of the evaluation, the team has eight PhD students. These research scientists also teach in five engineering schools. Some of the PhD students have teaching duties at the undergraduate level. The possibility of combined internships between Inria and California Institute of Technology (with Mathieu Desbrun) is also attractive to students.

Principal Strengths and Weaknesses

The group's research yield is very high in applied mathematics for computational geometry, computer vision and more recently ML techniques with extremely relevant results in recovering geometry and topology from complex outdoor and indoor scenes. They have set up an emblematic industrial transfer by making a sustainable contribution to the world-renowned open-source framework, CGAL. The establishment and continuous relationship with their spinoff, Geometry Factory, is a very important factor in their capacity of financing a decent pool of engineers being able to maintain their software tools.

One of the rare weaknesses of TITANE is the small size of the team and the fact that Pierre Alliez is moving to a new position, which could impact the team stability (see below).

Future Plans

TITANE wants to maintain their efforts in applied mathematical research (optimal transport, mixed-integer solvers) for geometry processing.

They intend to improve their large-scale city modeling with a new approach to integrate non-geometrical physical structure or urban function of complex scenes. They also want to provide generic output models to extend the range for different usages or different formats. New explorations will also concern dynamic geometry data structures as well as satellite image vectorizations.

TITANE also intends to extend their ML techniques to integrate adaptive priors in 3D scene modeling, to define error metrics in approximation and discretization of geometry modeling, and to learn architectures for onboard aerial and satellite image analysis.

Opportunities and Risks/Difficulties

TITANE seems to be sensitive to the necessity of dealing with an increasing number of distributed sensors such as smartphones, which implies a less centralized acquisition process with imperfect data, as well as online algorithms. This has already been taken into consideration with the ANR challenge project LOCA-3D, dealing with online localization and mapping, and through the collaboration with Google for networked environments.

The team also wants to explore new challenges such as geometric simplification of satellites for thermal simulation with DOREA. In addition, they mention their interest in effective simulation of elastic deformation of organs, for computer-assisted medicine.

Distributing efforts across many different domains could make it difficult to obtain significant results; however, TITANE has already demonstrated their ability to achieve successful outcomes across a range of communities.

TITANE is also looking for opportunities to enter collaborative European projects (in addition to prestigious ERC grants) to be able to set up an EU infrastructure project around the CGAL framework.

Recommendations and Suggested Measures of Success

The promotion of Pierre Alliez to the position of Head of Science emphasizes the need to find a fourth Research Scientist for the team, ideally combining expertise in ML and Geometry. It would also be beneficial to TITANE to add new senior postdoctoral fellows who can advise more doctoral students, so that they can expand the scale and number of their future projects.

The rise of lightweight low-cost sensors, such as smartphones, with distributed architectures, could be a good opportunity for TITANE to become part of collaborative European projects with strong industrial and societal impacts.