Step 2 Evaluation Report

CONFIDENTIAL

Call reference	ERC-2010-AdG
Activity	ERC Advanced Grant
Funding scheme	
Panel name	PE6 - Computer science and informatics
Proposal No.	267916
Acronym	ECSYM
Applicant Name	Glynn Winskel
Title	Events, Causality and Symmetry-the next-generation semantics

PANEL MARKS

1. Principal Investigator ***Quality of research output/track-record:*** *How well qualified is the Principal Investigator (and any co-Investigator if applicable) to conduct the project (reviewers are expected to evaluate the quality of the prior work such as published results in top peer review journals as well as other elements of the Principal Investigator's CV), taking into account the early or more mature phase of his/her transition to independence, as well as prior career breaks and/or unconventional research career paths (especially in the case of women scientists).* *To what extent are the publications and achievements of the Principal Investigator groundbreaking and demonstrative of independent creative thinking and capacity to go significantly beyond the state of the art?* *To what extent does the quality and quantity of funding the Principal Investigator has attracted during the last ten years demonstrate his/her reputation as a performer of ground-breaking research?* ***Intellectual capacity and creativity:*** *To what extent does the Principal Investigator's record of research, collaborations, project conception, supervision of students and publications demonstrate that he/she is able to confront major research challenges in the field, and to initiate new productive lines of thinking?*	**3.75 / 4**
2. Research project ***Ground-breaking nature of the research:*** *Does the proposed research address important challenges at the frontiers of the field(s) addressed? Does it have suitably ambitious objectives, which go substantially beyond the current state of the art (e.g. including inter- and trans-disciplinary developments and novel or unconventional concepts and/or approaches)? How well conceived and organized is the proposed activity?* ***Potential impact:*** *(a) Does the research open new and important, scientific, technological or scholarly horizons?* *(b) Will the project significantly enhance the research environment and capabilities for frontier research in Europe (including the host institution)?* ***Methodology:*** *Is the proposed research methodology (including when pertinent the use of instrumentation, other type of infrastructures etc.) comprehensive and appropriate to the project? Will it enable the goals of the project convincingly to be achieved within the proposed timescales and resources (including the costs of the Principal Investigator and the members of the team who will be engaged in the project) and the level of risk associated with a challenging research project?* ***High-gain/High-risk balance:*** *a) does the proposed research involve highly novel and/or unconventional methodologies, whose high risk is justified by the possibility of a major breakthrough with an impact beyond a specific research domain/discipline?*	**3.5 / 4**
Total mark	**7.25 / 8**
Has the proposal passed the thresholds (2/4) for criteria 1 and 2?	**Yes**

3. Research Environment ***Contribution of the research environment to the project:*** *Does the host environment provide most of the infrastructure necessary for the research to be carried out? Is it in a position to provide an appropriate intellectual environment and infrastructural support and to assist in achieving the ambitions for the project and the Principal Investigator?* ***Participation of other legal entities:*** *If it is proposed that other legal entities participate in the project, in addition to the applicant legal entity, is their participation fully justified by the scientific added value they bring to the project?*	**passed**

PANEL COMMENT

This evaluation report contains the final marks awarded by the ERC review panel during the second step of the ERC Advanced Grant review. The panel based its appraisal on prior individual reviews conducted by panel members and external referees. The comments of the individual reviewers are included in this report.

The panel closely examined all the individual reviews which were the basis for the discussion and the final recommendation of the panel. While not necessarily subscribing to each and every opinion expressed, the panel found that they provide a fair overall assessment, indicating both essential strengths and possible weaknesses in the proposal.

The proposal received strong support from the reviewers and the panel. All acknowledge the high-standing of the PI and his ability to undertake this programme of research. Moreover, he has assembled an excellent team.

The proposed research was judged to be innovative and world-leading. The proposal gave a good account of the work to be done and a detailed plan of how it would be tackled.

An adjustment was made to the budget to reflect the discrepancy between the statement of the commitment of the PI in the text and in the table. In the text it is stated that the PI will devote 8 months of the year to the project (66.67%) and a sensible justification of this level of effort is given, whereas the table claims a commitment of 80%.

The panel therefore recommends that the proposal should be retained for funding with a grant not exceeding 2 348 000.00 Euro.

REVIEWER COMMENTS

Reviewer 1

1. Principal Investigator:

Quality of research output/track-record:

The PI is among the top five experts in denotational semantics worldwide. He carried out groundbreaking work in the late 80s and early 90s on the semantics of concurrent systems. He is often identified as the top researcher on the categorical approach to denotational semantics, and has attracted a large amount of first-class funding during his career. On the other hand, his research area, while still strong in the UK, has become more distant from the mainstream in other countries. As a consequence, the work of the PI in the last decade, while still of excellent quality, has had smaller impact than his work during the previous decade. This is reflected in the comparatively lower number of citations of his publications of the last 10 years: none of them reaches 100 citations, and only two have more than 50.

Intellectual capacity and creativity:

The PI is a world-class researcher in the area of categorical denotational semantics, in particular for concurrent and distributed computation. In the past, he has produced some of the deepest ideas in the area, and all signs indicate that he will continue to do so: he is extremely active, and supervises students at the highest level. On the other hand, his research area is becoming more specialized and more distant from the computer science mainstream, which reduces the possibilities of collaboration outside his field and of having impact in other areas.

2. Research project:

Ground-breaking nature of the research and methodology:

The research proposal is very good. It has both depth and breadth, and an excellent top-down structure. The identification of symmetry as a key issue with consequences in many areas is highly original and thought provoking. At the same time, the proposal addresses a problem that was already clear in the early 80s, namely the fact that ”classical domain theory does not scale up to the more intricate models used in interactive/distributed computation”. The last 30 years have shown that this problem is intrinsic, and we will never have a fundamental and comprehensive semantic theory of concurrency with the same degree of canonicity as for sequential computation. This point is not sufficiently discussed and reflected in the proposal. In particular, one would have expected a stronger focus on specific application areas.
High-gain/high-risk balance and potential impact:

The proposal is likely to have major impact within the PI's research area of categorical semantics for concurrency. No university but Cambridge can set up a team of such quality (Fiore, Hyland, and Pitts are all world-class researchers), and if the proposal gets funded it will certainly and definitely establish Cambridge as the world-center in the field. At the same time, it will not have a major impact in other areas.

3. Research environment:

Contribution of the research environment to the project:

There is no doubt whatsoever that Cambridge provides the perfect environment for this proposal. It is already the stronghold of research in this area.

Reviewer 2

1. Principal Investigator:

Quality of research output/track-record:

The PI is indeed well qualified to conduct this project, being one of the world's leading workers in the denotational semantics of programming languages. He is the author of a leading textbook in the area. He has consistently worked on the semantics of concurrent, distributed computation, establishing a very influential approach. This began with his thesis where, among other things and with others, he established the fundamental notion of event structure, and linked it with Petri nets and with domain theory, thereby connecting two completely different areas of semantics. He went on to greatly deepen this work, showing how one could form categories of such structures, relate them by adjunctions and use categorical constructions to explain program constructions. (One should also mention that these connections enabled him to contribute very significantly to domain theory itself.) Then, with Joyal, he gave a fundamental abstract account of bisimulation in terms of open maps. This led naturally to work on profunctors to model computation, e.g. dataflow, and recent exciting (joint) work of his found the link with (spans of) event structures. Most recently, he has produced strong evidence that introducing a suitable notion of symmetry is the missing link for a well-rounded theory: indeed, that is the cornerstone of the present proposal.

In terms of state-of-the-art, he has consistently established the state-of-the-art; indeed, without his, and his collaborators', contribution we would not know anything near as much as we now do. As regards funding, one should mention the Aarhus BRICS Graduate School whose funding he and Nielsen secured and which he established and ran. While that lasted, it was absolutely the leading graduate institution in theoretical computer science, particularly semantics, in Europe. A good deal of the research mentioned above, and related excellent work, was done there by students under his supervision.

In the work on theoretical computer science, one expects numbers of small grants rather than single large ones (other than for collective endeavours such as BRICS). In that respect, the PI has done well with EC, UK EPSRC, and Royal Society Leverhulme funding. The various students, research assistants and visitors he funded are all top notch. He also has a fine reputation in the community at large, having invitations to speak at, and contribute to the organisation of, all the leading conferences in his area: LICS, CONCUR, MFPS, etc. He also has other significant professional recognition including a prize and editorships of leading journals in his field.

Intellectual capacity and creativity:

The major challenge that the PI faces is how to account for concurrent processes in a mathematically elegant and productive way that at the one time overcomes difficulties in the current state-of-the art and at the other fruitfully addresses current practical problems. His record of research gives one entire confidence that he can do this. In general terms, he has consistently developed a single approach, that of event structures. The development has been in no sense mechanical. One can mention his great work, with Joyal, on a categorical understanding of bisimulation; that led to the use of profunctors to model concurrency; that in turn led back to event structures, but now in a mathematically more sophisticated and flexible way, tying them in with profunctors, clarifying the need for a higher-dimensional approach, and bringing in, for the first time, the idea that a treatment of symmetry is, as in so many areas of mathematics and science, fundamental. So much for the PI's ability to advance the needed scientific and mathematical understanding at a theoretical level.

He has also shown very strong ability to apply these ideas. For example, he established a strong presence in security with his work on strand spaces, and there he has interacted fruitfully with Guttman, at MITRE, the inventor of strand spaces. As another example, he has recently began working with the very strong group around the kappa system for systems biology, comprising Fontana at Harvard, Danos at Edinburgh, and Krivine at Paris; this group is interested in the right, better most useful, definition of event in a stochastic intracellular simulation. As the PI himself says, events, and their organisation into event structures, occur in many areas of computer science and that makes his general applicable view of central importance.

This ability to undertake prolonged intellectual journeys indicated by current understanding and yet to come back and integrate with previous views, leading to ever-deepening understanding, is exactly what one needs for the PI's project of a new higher-dimensional denotational semantics of programs, particularly concurrent ones. On a more mundane level, he has shown himself able to collaborate with leaders in their various fields, such as Nielsen, Joyal, Fontana, Panangaden, etc., to inspire postdocs, and to lead graduate students. As a relevant statistics, he has 38 co-authors in DBLP (although that includes some co-editors). Neither is he lacking in productivity, with over 90 publications over 20 years.

2. Research project:

Ground-breaking nature of the research and methodology:

There is no doubt that the research addresses important and fundamental challenges which go well beyond the state of the art in the semantics of programming languages. Having said that, the methodology is founded on many years of prior work by the PI, which has led to the proposed methodology. What he has achieved is a consistent and already well tested mathematical apparatus, which gives him the means to look beyond with confidence: one can use his current ideas, as he describes in the proposal, to understand that what is being proposed is within reach, although a huge amount remains to be discovered. Four years is about the right length of time for the work, and the team represents a fantastic resource: the junior members can advance specific projects and the project meshes perfectly with the various research programmes, already established, of the senior members of the team. The PI can interact with them as appropriate.

The fundamental methodology is the development and application of ideas from event structures, guided by the "first-generation" work on denotational and operational semantics of programming languages, but with an eye to the specific needs of concurrency, with the foreknowledge that higher-dimensional algebra will be appropriate, and with a fair idea of where the mathematical development needs to go - specifically the systematic treatment of symmetry.
Here are some illustrative remarks on specific parts of the research proposed. The remarks are indexed by the corresponding parts of the proposal:

1.1. This part continues the present work reconciling profunctors and spans, and proposing a metalanguage along the lines of Moggi's. This perfectly illustrates the methodology, solidifying the event structure ideas, and testing them by seeking an analogue to a major first-generation achievement. The result would be a general metalanguage for concurrency, a fascinating thought.

1.2. This is work begging to be done. The best intensional first-generation work is game semantics, and surely event structure ideas here are the natural way to advance this theory, which, while successful, lacks structural understanding.

1.3. The methodology of using symmetry should work well here, and there must be a connection with nominal sets. Pitts, one of the senior figures involved, is the world authority in the area of nominal sets.

1.4. Event structures are concrete examples of the kind of higher-order algebras needed. The corresponding first-generation ideas may be those of the algebraic theory of effects. Here Marcelo Fiore and Martin Hyland, other involved senior figures, are again of world strength. The methodology of taking the main "examples" viz. various categories of event structures and treating them abstractly is entirely appropriate.

2.2. Event types and their logic. The idea of domain logic at the categorical level is fascinating: one imagines that one would talk of realizers rather than truth.

3.1. There is already a notion of probabilistic event structure, due to the PI and others, but the proposal here is to incorporate symmetry, and more than that: to incorporate other computational effects such as nondeterminism and names. Doing these important cases should be very fruitful. For example, one can imagine a treatment of security of distributed systems taking probabilistic protocols into account - something that has so far resisted researchers.

3.1.-3.2. The ideas of stochastic or quantum event structures are novel and exciting, and provide evidence that the main notion, of event structures, gives a solid basis for extension.
High-gain/high-risk balance and potential impact:

The idea of using event structures as the basis for well-founded higher-dimension semantics of programming languages is unconventional and novel. As a formal possibility, the thought of higher-dimensional semantics has been known for a long time but, presumably, was never developed as the possible payoff was not clear. However, with the knowledge we now have from the PI's research, the point is clear, both in terms of the scientific problems it addresses and also as regards (something of) the scope of the possible applications. There are possible breakthroughs: either of stochastic event structures or quantum event structures could have major applications in other domains than standard theoretical computer science, viz. systems biology or quantum computation. For example, there is currently no denotational treatment of languages for quantum-mechanical message-passing, even though there are already commercial systems available for such message-passing. More broadly, the research opens out the prospect of a new view of the semantics of programming languages, not only as regards the particular research problems chosen, but rather as regards them as a totality. The proposal seeks to understand the semantics of concurrent computation in a way that is analogous to first-generation semantics. Further, it seeks to do so while integrating intensional aspects such as game theory and operational semantics. The significance of this for the field is that around the 80's it split, roughly speaking, in two. One part advanced the treatment of sequential computation, where, for the most part, development of first-generation methods suffices; the other part advanced the treatment of concurrent computation, where most of the first-generation treatment did not suffice, and one had to make do, however successfully, with operational means. This was particularly true for non-interleaving concurrency, increasingly important for distributed computing, where only operational models were available. The PI's proposal should help reunite the area as regards non-interleaving (and may also lead to insight on interleaving).

The research will help place Europe in a leading position, or at least substantially strengthen its position, in several areas: the semantics of concurrent computation and its applications, including security, trust; systems biology; quantum computation; and weak memory models. In this way, Europe will be at the frontier as regards its scientific basis for the advancement of programming languages for concurrent computation (whose applications range from the micro scale, as in biology and physics, to the macro scale, as in the internet, where non-interleaving computation is the standard). Cambridge is already a leading centre for work on the semantics of programming languages; it has a strong permanent staff in the area (the PI and the senior researchers); it has (intermittently funded) very strong junior members; and it always attracts the best postgraduates. The award of this grant would take them to a new level of funding, especially with the time released for the senior members and the long-term establishment of a team of junior researchers. This would surely have a very significant knock-on effect for the UK work in the area, as well as for a number of European centres (for example, one immediately thinks of various leading researchers in France, Denmark, Italy and Germany).

3. Research environment:

Contribution of the research environment to the project:

Other than reasonable computational facilities and a pleasant working environment - all of which Cambridge provides - little is needed in the way of infrastructure for a programme of this kind. The key thing is the quality of the intellectual environment - the people. Britain is particularly strong in the area of the semantics of programming languages and Cambridge now has the strongest representation of any UK university in the area. Many of these players are in the team the PI has assembled. Indeed, he has gotten hold of just the right selection of people. Martin Hyland is a categorical logician acutely knowledgeable of the higher-dimensional algebra needed for the project; Andy Pitts is the inventor of the nominal approach now widely used for understanding fresh names - a crucial part of the project; Marcelo Fiore is very strong in the application of categorical methods, having, for example, made major contributions to the mathematical understanding of operational semantics, another essential part of the project. All three are internationally leading researchers in semantics and logic in their own right: a full account of their many and varied achievements would take several referee reports in itself.
As regards the junior members of the team, Sam Staton is definitely one of the leading young workers in the area, and he has already shown by his contributions that he is a needed part of the team for this project. Both Jonathon Hayman and Chung-Kil Hur have done good work in the area; perhaps the former's contributions are the stronger. Richard Garner will certainly help with the needed background in categorical algebra. Beyond the immediate team, Cambridge provides a directly relevant wider intellectual and scientific context. In general terms, the work proposed is, in large part, theoretical, but with application firmly in mind, and there are several people one can mention who are well-versed in various such applications and who will certainly further enrich the project. For example, Peter Sewell is an expert on weak memory models and their semantics, one of the project application areas; Mike Gordon and Larry Paulson are world leaders in computer-assisted theorem proving: that may well help with the anticipated work on reasoning; Andrew Phillips and Luca Cardelli, in the nearby Microsoft Research Cambridge Lab, and Michael Pedersen, in Cambridge Plant Sciences, provide expertise on systems biology; others in Microsoft Research provide broad expertise in programming languages, their semantics and their implementation, and still others have expertise in the kind of logics that will be needed, such as spatial logic and separation logic, a la Reynolds. It goes without saying that the PI has a strong connection with the relevant leading researchers internationally, but one might mention some in particular. He has a longstanding collaboration with Nielson at Aarhus, now working on models of trust. He has a well-established relationship with Guttman at MITRE and his work on strand spaces in security. He has recently developed what has already proved to be a fruitful working relationship with the kappa-team, such as Vincent Danos at Edinburgh and Walter Fontana at Harvard. All of these relationships will play an important and fruitful role in the project.

Reviewer 3

1. Principal Investigator:

Quality of research output/track-record:

The PI is perfectly qualified to conduct the proposed project. The PI is almost the only researcher which adds up all the requirements to lead this project. His publications are in large number for this kind of mathematically-oriented computer science and are on top scientific journals. His main achievements helped often to start new research lines, which were eventually quite fruitful.

The funding in this area is mainly for PhD students and postdocs. The PI was quite successful in both raising the funds and in nurturing very valuable researchers.

Intellectual capacity and creativity:

The PI has a very good network of researchers and sites he is in contact with. He had about 20 PhD students, some of which became well known in the area. Here the notion of project is different and less structured than in other more applied areas of computer science. However, as I mentioned previously, his research, while sometimes arcane, is usually quite innovative and follows general, systematic lines of development.

2. Research project:

Ground-breaking nature of the research and methodology:

The proposed research is about developing a notion of general (i.e. monad-enriched) span of event structures with symmetries as a new, general semantic model. The proposal can be considered as the synthesis of life-long efforts by the PI and adds to the original notion of event structure, as introduced in the PI's PhD thesis, a number of new dimensions: (i) input-output and compositionality, via the span structure and monad enrichments à la Moggi, (ii) names, via a presheaf structure or equivalent, (iii) a (weak) bisimulation-based abstract semantics, via spans of open maps à la Joyal, but possibly also via coalgebras and bialgebras, (iv) higher order, (v) probability, or in general quantitative concepts, as in recent work by Varacca and the PI.

The combination of so many dimensions is by no means a trivial task. The proposed structure (models, reasoning, quantitative extensions, applications) is fine. What is to some extent missing is the identification of existing challenges which could be solved only using the proposed approach. Several are mentioned, with existing known, possibly limited solutions. The novelty is that they should be solvable within a unitary framework.
High-gain/high-risk balance and potential impact:

The proposal plans to apply well established semantic methodologies. The history presentation tends to underestimate the present state of the art to highlight possible improvements. Also, it is quite Cambridge-centric, while other approaches have been published which could be considered advantageously.

Of course, the positive impact could be that general results inspire similar constructions in different areas. However, results, to be very general, may be at a very abstract level: the additional constructions needed for generality may be obscuring in particular cases. Understanding the results may require difficult mathematical concepts, which may introduce additional complexity.

In conclusion, the proposal is very interesting and innovative, but to some extent self-referential and with a mainly technical impact.

3. Research environment:

Contribution of the research environment to the project:

The Cambridge environment, together with the existing (mainly European) external connections, can be considered perfect. In particular, the collaboration with the Mathematics department and the participation of Marcelo Fiore, Andrew Pitts and Sam Staton is exactly what is needed for the project.

Reviewer 4

1. Principal Investigator:

Quality of research output/track-record:

The PI definitely has the track record needed to carry out the research proposed.

Intellectual capacity and creativity:

The PI definitely has the intellectual capacity and creativity necessary to carry out the research proposed.

2. Research project:

Ground-breaking nature of the research and methodology:

The proposed research is solid work following up a solid and well established line of research.
High-gain/high-risk balance and potential impact:

The project will definitely produce top level research. The high risk/high gain as well as the potential impact are not so clear.

3. Research environment:

Contribution of the research environment to the project:

The host institution definitely has the necessary infrastructure.

Reviewer 5

1. Principal Investigator:

Quality of research output/track-record:

The applicant has, throughout his career, conducted foundational work with wide-ranging and long term impact, often long after the original work was published. He has sought to develop deep understanding, and through that understanding to unify theories. His work has been influential and taken up by many other researchers. He has a reasonable track record of individual research funding and maintains an international profile through numerous editorial boards, committees and invited talks at prestigious conferences.

Intellectual capacity and creativity:

The applicant's track record shows that he has supervised a substantial number of PhD students and young researchers, and has long-standing collaborations with other leaders in the field. Previously in Denmark, he very successfully led a large research undertaking. His previous work and the citations it has attracted show that he is capable of making original contributions which have impact in the field.

2. Research project:

Ground-breaking nature of the research and methodology:

This is a beautifully written proposal. The planned work is clearly motivated, the approach to be followed is explained in appropriate detail, and clear objectives are identified. The work is foundational and timely, offering significant intellectual challenge. It is likely to stimulate a great deal of further work in a topic where Europe is already internationally leading. The PI and his assembled team of world leading researchers are uniquely qualified to undertake this programme of work. The scale of the project is appropriate for the scheme, requiring an ensemble and protracted effort which would be difficult to fund under a national scheme. It may be that not all the goals identified within the proposal will be achieved within the project lifetime, but there is very little risk that there will not be substantial outcomes of the project. A broad range of potential application areas are identified with appropriate collaborators for each one.
High-gain/high-risk balance and potential impact:

The proposed project builds upon foundations set by the PI and others over the last ten years and thus does not represent a radical new departure, more an opportunity to bring various concepts together to address a long-standing problem of denotational semantics. The impact is not likely to be felt in the commercial world during the lifetime of the project. Nevertheless, the work will help to keep Europe at the forefront of an area where it is currently world-leading.

3. Research environment:

Contribution of the research environment to the project:

The Computing Laboratory at Cambridge would clearly provide an excellent research environment, especially for this project.

Reviewer 6

1. Principal Investigator:

Quality of research output/track-record:

The PI is a researcher with a long and highly visible career, with very good citations on certain older publications and an impressive list of publications. The area is a classical one.

Intellectual capacity and creativity:

The PI has produced some extremely high-quality work in this classical area, perhaps staying mostly on the established fields. The work has clearly been very influential.

2. Research project:

Ground-breaking nature of the research and methodology:

The aims of the project are very ambitious, and clearly the proposed project addresses several undoubtedly fascinating questions. In this sense, the project proposal is clearly excellent. One caveat has to be added, though. The extended synopsis argues extremely well the questions "how?", "what?", and "why this PI and this team?", but the first question "why?" is not perhaps as clearly answered.
High-gain/high-risk balance and potential impact:

A question that can be asked is: what happens if this project is completely successful?, what will change? The project is very interesting in many respects. While there are many difficult and fascinating questions in the area, one can wonder slightly about the potential impact. The applications mentioned are in distributed and parallel computation and in systems biology. This reviewer is not completely convinced that Petri nets etc. (the PI uses the term “causal models”, which has many interpretations) are good models to be used in systems biology, where the probabilistic nature of the events is perhaps the most important thing to be modeled. While some of the event structure models have a probabilistic counterpart (e.g. in the PI’s co-authored paper Probabilistic Event Structures and Domains), it seems that systems biology needs a fully probabilistic approach.

3. Research environment:

Contribution of the research environment to the project:

The environment is clearly adequate for this project.

Reviewer 7

1. Principal Investigator:

Quality of research output/track-record:

The PI is a leading figure in the semantics of computation. He has an excellent track record.

Intellectual capacity and creativity:

The PI has been responsible for many innovative ideas in semantics and logic of computation.

2. Research project:

Ground-breaking nature of the research and methodology:

The proposal is ambitious in seeking to go well beyond the current state of the art in extending the scope and applicability of causal models. A rich and diverse research program is clearly set out in convincing detail.
High-gain/high-risk balance and potential impact:

Causal models are already widely used, in a variety of guises. The proposed research would unify these developments, and very considerably extend their scope, e.g. towards higher-order processes, or the use of causal models such as Petri nets for giving structural operational semantics definitions. There are significant mathematical challenges along the way, which are of interest in their own right. The risk is that some of the many directions mentioned may not pan out. But it seems very likely that significant progress would be made, on a number of fronts.

3. Research environment:

Contribution of the research environment to the project:

The research environment is very strong, which would be most appropriate.

Reviewer 8

1. Principal Investigator:

Quality of research output/track-record:

In terms of measures such as his publications and other research achievements, the PI is one of the best researchers in the world in the general area of programming language semantics, and probably the best in the specific area of the proposal.

Intellectual capacity and creativity:

New productive lines of thinking is exactly what the PI's research record is about. There is a major approach to semantics that he invented and in which he is the leading researcher. And it fits the work in this proposal like a glove.

2. Research project:

Ground-breaking nature of the research and methodology:

The ground-breaking nature of the proposed research lies in its potential to unify the field of programming language semantics. The field is beset by a kind of balkanization in which bright ideas usually proliferate more than they interact. In such a milieu, the best research is research that unifies. The PI hopes to break through the tripartite division - between denotational, structured operational, and causal semantics - to develop a single approach that integrates all three. Perhaps this sounds like hype, but the cogency of what he proposes (and in particular the fascinating ramifications of his notion of symmetry) makes it a much more than plausible claim.

High-gain/high-risk balance and potential impact:

As in all significant research, there is novelty that imposes risk. But it is more than justified by the potential rewards. This reviewer is particularly excited by the potential application to concurrency, where the limitations of conventional (e.g. interleaving) semantics have become all too evident, and a causal approach is likely to be the wave of the future. In this area, the potential for progress far outweighs the risk.

3. Research environment:

Contribution of the research environment to the project:

Cambridge University is the best environment for pursuing research in this area in the world. The group of senior associates that the PI lists is also admirable, both in overall quality and in appropriateness to the proposed research.