EIVIS : What Emerges when *in vivo* meets *in silico*

A Research Cluster for Novel Computation Architectures

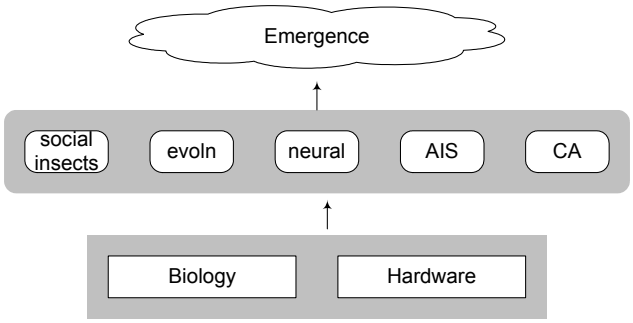
Individual Grant Review (IGR) report

GR/S63823/01

Note: A Research Cluster project resembles a Network more closely than a research project, and so this report has been written following Network Grant guidelines, where applicable.

Background/context

Our Research Cluster has developed an innovative research proposal for a 5 year interdisciplinary research project to tackle the problem of designing robust complex computational and engineering systems, by taking inspiration from biology. We have exploited and combined our expertise of *in vivo* (biological) and *in silico* (physical hardware) systems, to develop a proposal to build both experimental and theoretical research models of how **robust** global behaviour **emerges** from the complex dynamics of vast numbers of interconnected imprecise and fallible agents (neurons, cytokines, cells, social insects, processors), all operating with no need for centralised control.



Our Research Cluster operated for six months, initially devising a coherent strategy and inviting suitable further members to join, and subsequently dividing into a few small sub-groups to develop specific parts of the proposal. The funding supported innovative brainstorming and proposal drafting meetings, visits to members' and others' sites, and Web site coordination.

Project Activities

The aim of the cluster, in addition to developing an innovative research proposal, was to build a cohesive team by innovative facilitated brainstorming techniques. We spend some time describing the process by which these aims were achieved.

Innovation Lab (July, and August)

The two initial brainstorming workshops were facilitated by the **Innovation Lab**, at Rugby.

The PI visited the Rugby Lab as soon as the Cluster was given the go-ahead, to investigate the facilities, to arrange the structure of the brainstorming workshops with the facilitators, and to set targets and goals for the first meeting.

The kickoff meeting in July was a two day residential workshop at the Rugby Lab. This provided a venue and environment for 11 of the core team members, many of whom had previously met only electronically, to get to know each other. The relaxed atmosphere of the Lab, and the skill of the facilitators, soon had ideas flowing. The meeting was kept deliberately informal: there were no member presentations or other "academic" sessions. Instead, the entire group repeatedly broke into separate sub-groups, and reformed, allowing ideas to form, mix and reform fluidly. As is typical in these kind of events, the first major innovative idea gelled in after-dinner discussions, and was built on the following day. This idea was to form a project with two different axes of investigations. It was discussed with interest, but failed to gel fully until the second workshop. However, sufficient groundwork was laid to enable the team to contact new members in relevant areas.

The part time RA support was used to set up and manage a Web-based discussion forum, to enable the cluster members to communicate readily, and to provide a repository for project documents.

The second workshop was another two day residential event at the Rugby Lab, in August. In the intervening month, new members had been contacted, or had approached the cluster. This new membership, plus a representative from EPSRC, were introduced to the Rugby style, and the workshop then took off where the previous one had stopped. (This workshop also had 11 members, although with slightly different membership from the first meeting.) The brainstorming produced a range of key questions thought to affect complex behaviour in general, and robustness in particular. These were organised under the headings of Openness, Diversity, Interaction, Structure, Scale. At this point the previous "two axis" approach finally gelled. The "horizontal" axis comprises investigations into bio-inspired robustness across a range of exemplar domains, building better biological models, and associated well-grounded computational frameworks in each domain. The "vertical" axis integrates, generalises and enhances the findings from these various domains. This approach would allow the individual bio-inspired computational frameworks to be analysed and combined in a way to produce genuinely novel computational approaches not accessible by examining a single biological domain alone.

It was clear that it would be relatively easy to produce "conventional" style proposals in individual domains, but that the "two axis" approach would provide substantial added value. We realised that the individual domain models would not fit perfectly into an integrated model: one exciting part of the proposed research would be to expose essential differences between these domains, as well as to integrate common abstractions. We also realised that not only could we validate the integrated model by specialising it and instantiating it with the concepts of each of the exemplars, and those from suitable external models, but that we could additionally provide a

novel instantiation, thereby building an example computational framework inspired by biology, but not restricted to any one particular biological domain.

Excited by this idea, we discussed the best approach to take. Encouraged by the EPSRC representative to remember the mandate to be innovative, we decided on a "high risk" approach, to produce a *single* proposal that incorporated several exemplar strands, with the integrative strand providing added value and innovation. This decision shaped the rest of the cluster lifetime, and caused a fairly substantial deviation from the original project plan of developing several separate proposals. The structure of the various strands was established, and sub-group membership arranged. The three exemplar domains were chosen based on several criteria: sufficient expertise and interest amongst the cluster membership, sufficient existing biological results to provide valuable input, sufficient opportunities for mathematics and computer science to provide improved biological models, sufficient complexity to provide rich new computational frameworks, sufficient familiarity to devise validating demonstrators, and sufficient diversity of ideas, concepts, and theories for integrated higher level analytical models and frameworks to be developed. The three biological domains chosen were metabolic and signalling networks, immune recognition, and neural structures.

A key feature to note is that sub-group membership overlapped: most team members were in at least two sub-groups. This occurred naturally, and was a key feature of keeping the entire proposal a unified whole.

Individual sub-groups (September, October)

Over the next two months, the three exemplar sub-groups, and the integration sub-group, met electronically, and in special meetings, to invite further new membership into the agreed upon strands, to thrash out the details of the specific sub-projects, and to ensure that they fit into the overall proposed project structure. This task was greatly eased by the ready rapport evident in the cluster, established at the Rugby workshops.

USA visit (October)

One major task was a visit by the 6-member Integration sub-group to various researchers in New Mexico, USA. New Mexico has one the world's greatest concentration of researchers in the area of complex systems and bio-inspired computation. The sub-group met with

- Professor Stephanie Forrest and her Artificial Immune Systems research group at the University of New Mexico
- Visualisation researchers Dr Tom Caudell (Albuquerque High Performance Computer Centre) and Steve Smith (Los Alamos National Laboratory)
- various researchers at the Santa Fe Institute
- Complex Systems researcher Norman Johnson (Los Alamos National Laboratory)
- Steen Rasmussen and Norman Packard, PACE project
- Stuart Kauffman

The sub-group presented the proposed ideas, and discussed the work with all these researchers. All were very keen and supportive, and many agreed to be collaborators in the proposal, and to provide further "external" exemplar projects. These presentations and discussions provided the sub-group with valuable validation of the integrative approach, and several new ideas to incorporate into the proposal.

Proposal drafting workshop (November)

16 members of the cluster reconvened for a "proposal drafting workshop". This three day event in York finalised the conceptual framework used to structure the proposed research, and finalised the detailed structure of the exemplar projects. All that was left now was to write the proposal itself!

Proposal writing (December, January)

Over the remaining two months before the submission deadline (which included the Christmas break), the proposal was assembled electronically. The various sub-groups provided input for their work packages, and the PI drew the pieces together. Again, this task was eased by the existing rapport of the cluster members. Further evidence of this rapport and trust is shown by the ready agreement of all the cluster members to a subcontracting financial structure for the final proposal, the eagerness of several investigators to be involved in the project despite not directly getting any staff, and the volunteering of external effort (RAs and RSs) to support the proposed research.

Deviations from plan

The original plan assumed that several individual proposals would be produced and submitted, and had provision for many more meetings to achieve this. Consequently, since rather fewer meetings were needed, the cluster work came in approximately £13k under budget.

We believe the single proposal route has resulted in a higher quality, and more innovative, result.

Outcomes

Innovation Lab

The Innovation Lab provided the ideal initial environment for developing novel, exciting ideas, and building a team that worked together extremely well over the lifetime of the cluster.

The fact that so many senior people found time for several multi-day meetings, and other single day meetings, over the short timescale of the project, is evidence of our commitment to the proposed project approach. We believe the initial use of The Lab helped, by forming a team, and by resulting in innovative ideas that excited the team.

The use of facilitators also enabled all members of the cluster team to participate fully at the technical level, without having to worry about "running the meeting".

We highly recommend the use of The Lab as a productive "ideas" environment. We suggest that other researchers, and EPSRC, seriously consider using The Lab for their own projects.

Web Discussion Software

To facilitate electronic discussion amongst the cluster membership, a web-based discussion server was set up, using the BSCW Shared Workspace Server at York. This "groupware" provides discussion groups, a group diary, and a document repository.

Success was limited. The cluster members, particularly those less "e-aware", seemed to find it inconvenient to log on daily to see if new items were available. Also, the chosen software has a somewhat clunky interface, so the *very* e-aware got rather irritated with it. Eventually, the membership reverted to communicating by group email, and the web server was used purely as a centralised document repository, for the various proposal drafts, and the plan for assembling the drafting. The membership was small enough that email discussion worked. A larger group might have found this impractical, however.

This style of software should be reinvestigated for its effectiveness at supporting a larger group, over a longer running project, with more sub-structure. For it to work effectively, however, it is clear there needs to be an appointed web server manager, and possibly a short training session on how to use an unfamiliar interface for those less accustomed to this style of working.

ODISSIAC Proposal

The research proposal that resulted from the EIVIS cluster activity is dubbed "ODISSIAC". It is a 5 year, 10 person, interdisciplinary research project to tackle the problem of designing robust complex computational and engineering systems, by taking inspiration from biology.

Individual biological domains each provide their own different inspirations and viewpoints, but no single one encompasses all aspects of robustness. So ODISSIAC takes an integrative approach. Three specially designed exemplar subprojects, each delivering valuable biological and computational results in their own right, provide the foundation for an integrated development of novel computational algorithms. These would be used to produce powerful mathematical and computational models of metabolic networks, of immune recognition, and of neural structures, and would develop novel computational algorithms inspired by these new models.

ODISSIAC would additionally develop and populate a well-defined conceptual framework and process, in order to structure, analyse, and integrate diverse biological models and computational algorithms. This would be used to extend, generalise, and integrate the exemplar results, and furthermore to develop novel algorithms inspired by biology, but not restricted to any one particular biological domain. The aim would be to develop general design principles and analyses for engineering for robustness, and to build hardware engineering demonstrators of these principles.

To achieve these ambitious objectives, ODISSIAC comprises the eventual EIVIS cluster membership: an interdisciplinary team of academics and industrialists with internationally-leading expertise and excellent track records in these biological domains, in mathematical modelling of biology, in bio-inspired computer science, in bio-inspired electronic engineering, and in industrial applications.

Collaboration

ODISSIAC includes substantial industrial collaboration. BAE Systems, in particular, are proposing to devote considerable resource to the project, in terms of staff time (one person full time for the duration), equipment (robots and other engineering demonstrator support), and other facilities (hosting international summer schools).

The ODISSIAC structure has been designed to allow and encourage other, external, projects to contribute further "horizontal" inputs, and thereby receive ODISSIAC outputs covering their own topics. This would promote a co-ordinated structured approach across the whole of the research community, adding value to the research. This process has already started: initial contacts made during EIVIS have gained support from other internationally-leading groups, including the Santa Fe Institute. Additionally, cluster members have proposed to contribute additional staff to the project.

We envisage ODISSIAC as only the initial core of an ongoing research programme in novel bio-inspired algorithms and robust complex engineering. One key aim of the proposed project is to generate further research activity in this area, to continue this integrative approach after ODISSIAC itself has completed.

Conclusions

ODISSIAC is a highly adventurous interdisciplinary project, carefully structured to contain and manage risk. It will produce high impact results in the field of novel computation, integrating diverse bio-inspired domains. It will deliver a range of powerful sophisticated biological models; it will deliver integrated novel bio-inspired computational frameworks that will have a substantial impact on the way robust complex computational systems are understood and designed; and it will form the core of a flexible ongoing research programme.

The cluster approach has allowed the development of such an innovative proposal. It is highly unlikely that this would have occurred without the explicit funding to allow several large meetings, both internal to the cluster, and with other research groups.

Irrespective of the success of the proposal itself, the cluster exercise has built contacts and interdisciplinary relationships both within the group, and beyond the group, that have already continued beyond the lifetime of the cluster. In that alone, it can be considered a success.