The XPS project

Situation

"…we are looking at a paradigm in its youth, full of potential and fertile with new ideas and new perspectives…Researchers in many countries are experimenting with particle swarms…Many of the questions that have been asked have not yet been satisfactorily answered." [Kennedy & Eberhart, 2001]

PSO publication pattern

Year	Publications
1995	2
1996	2
1997	4
1998	12
1999	16
2000	18
2001	49
2002	106
2003	99
2004	???

Problem

There is as yet no structured body of knowledge that would tell someone without a research interest in PSOs which type of PSO is appropriate for a particular problem and conversely for which problems PSOs are the algorithm of choice.

Areas

- Many different variations of the basic recipe have been tried and compared to existing techniques
- Many different application areas have been investigated (from synthetic problems to real-life problems)
- Very few papers of theoretical significance

Aims

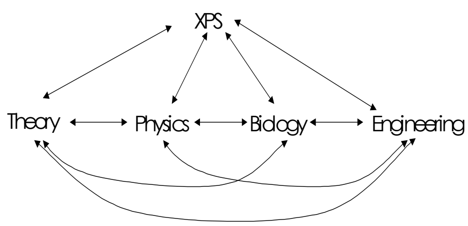
The aim of this project is to undertake a coherent and authoritative programme of work that will give a definitive account of the particle swarm paradigm, enabling the effective targeting of future work on an international scale towards clear scientific and industrial goals.

Aims

The aim of this multidisciplinary research project is to *systematically explore the extension of particle swarms*

- by including strategies from a wide range of collective behaviours in biology,
- by extending the physics of the particles,
- by generating an extensive set of engineering problems and a flexible simulation engine, and
- by providing a solid theoretical and mathematical basis for the understanding and problem-specific design of new particle swarm algorithms.

Project overview



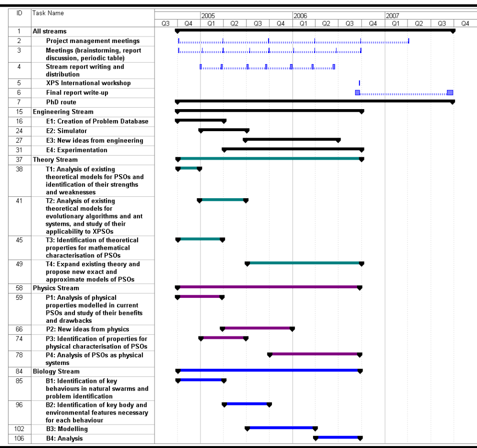
Programme

- *Theoretical stream:*
  - Extend the theory available to date on PSOs
  - Borrow theoretical concepts from the more developed theory of evolutionary algorithms

- *Biology stream:*
  - Take inspiration from biology to explore the space of swarm intelligence systems.
  - E.g. more sophisticated flock dynamics, more complex particles (provided with memory, state, metabolism, sensing, action selection, etc.).

- *Physics research stream:*
  - A PSO can also be seen as a multi-body physical system.
  - Can we take inspiration from physics to explore more complex particle interactions and environments?

- *Engineering stream:*
  - Evaluation of the practicality and relative merits of XPSs via implementation and testing on well thought out test problems
  - Identification of areas deserving further exploration and analysis during the project and in future research.
  - Extend the models beyond real biology and physics: exploration of *swarms as they could be.*



- **D3: Swarm intelligence periodic table**
- *The construction of this periodic table is the main challenge and scientific contribution of the proposed research.*
- SIPT is a categorisation of XPSs according to theoretical, biological, physical, and engineering criteria.
- An indication will also be provided as to
  - which models appear to show higher emergent behaviour and intelligence,
  - which appear to deserve more investigation,
  - which are more suitable for which application domains, and
  - which PSOs are conceivable but haven't been explored in the project.

Individual measurable objectives

- **D1:** a biologically and physically rich, realistic and extensible simulator of PSOs.
- Relevant descriptions of the physics of interacting particles, with and without bodies, with and without quantum effects, with and without friction and viscosity, etc.
- Algorithmic descriptions of animal behaviours to be made possible by the simulator.
- Recipes to ensure the stability of resulting PSOs and the well-behavedness of the numerical integration of the dynamic equations governing PSOs.

Objectives of this plenary meeting

- Getting to know each other and learning each other's language and objectives
- Summary of work done to date
- Brainstorming
- Identification of key questions and possible avenues to answer them
- Work-package allocation, site synchronisation (e.g. to avoid duplication of work and competition)
- Identification of possible 2- or 3-site collaborations
- Identification of objectives to be achieved by next meeting(s).

- **D2:** A mathematical characterisation of XPSs and a proof of convergence for the largest possible class of XPSs
- Theoretical models of XPSs and their extensions explored in the project.
- Most important modelling and analysis tools available in physics and theoretical biology.
- Corroborate the theory by gathering suitable empirical data using the simulator.

Some questions

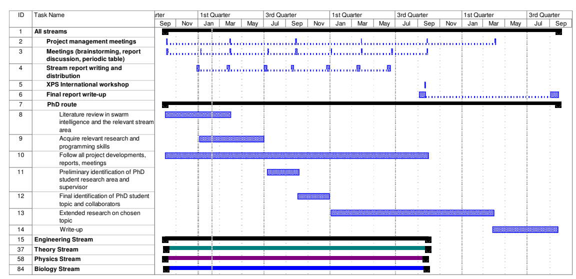
- What are the effects, both positive and negative, of coupling the equations of motion more tightly to both components and particles?
- What are the roles of random and deterministic forces?
- Could analogues of quantum effects, including the ability to tunnel through barriers, deliver benefits?

- What about molecular forces, or analogues of chemical interactions?
- Could force fields, perhaps of different types, be used to guide the search towards or away from certain areas?
- Could information carriers be used to provide forms of communication between particles?

Detailed Project Description

- What kind of mathematical models are appropriate to describe XPS?
- Can we borrow models from other areas of AI?
- What kind of behaviours should we borrow from biological swarms and why?
- Can we get intelligence, emergence, and complexity from XPSs and what do we mean by these terms?

All streams



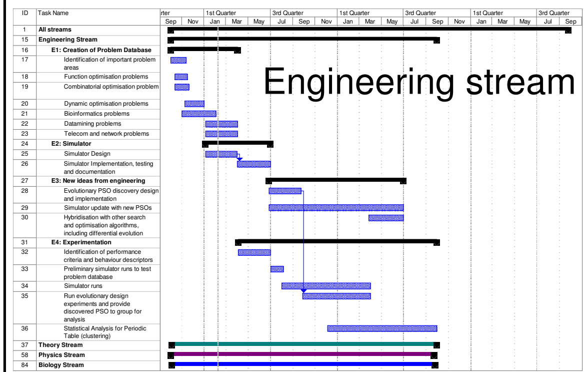
- What form would a swarm intelligence periodic table take?
- What quantities should we use to cluster (problem,algorithm) pairs?
- Is there any continuity in the space of XPSs?
- Can we apply the results of this work to biology?

Engineering stream

- **STAGE E1** (6 months) library of interesting static and dynamic test problems, including the real-world problems provided by BT Exact, data mining problems, bioinformatics problems and image-processing problems.
- Problem areas ranging from function optimisation to combinatorial optimisation problems, to dynamic optimisation problems and to telecommunication and network problems.

- **STAGE E2** (6 months, partly in parallel with E1 and E4) creation of an extensible XPS software simulator.
- A common computational framework for all the streams designed, implemented, tested and documented in an early stage of the project.

Engineering stream



- **STAGE E3** (12 months, largely in parallel with E4)
- Extension of the simulator with new XPS models and mathematical recipes coming from the other streams.
- Adding evolutionary capabilities to the simulator.
- Best evolved XPSs to be embedded in the simulator and studied extensively.
- Study *hybrid* PSOs suggested in the literature and propose new ones for inclusion in the simulator (GA-PSO, hill-climber/PSO, DE/XPS)

Theory Stream

- **STAGE T1** (3 months) Analyse existing theoretical models of particle swarms with the aim of identifying their strengths, weaknesses and potential for future extension.
- **STAGE T2** (6 months) Analyse existing theoretical models of systems with similarities to particle swarms, and study their applicability to XPSs:
  – Recent ant systems convergence proofs [44,16]
  – GA coarse grained models
  – Markov chain models
  – Theory of evolutionary strategies

- **STAGE E4** (18 months) extensive experimentation with the simulator and its evolutionary component.
- Identification of appropriate parameters for categorisation of the behaviour of XPSs and of objective criteria for the evaluation of their performance from the engineering point of view.
- Analysis of the evolved components will be performed to fully understand these new systems.

Theory Stream

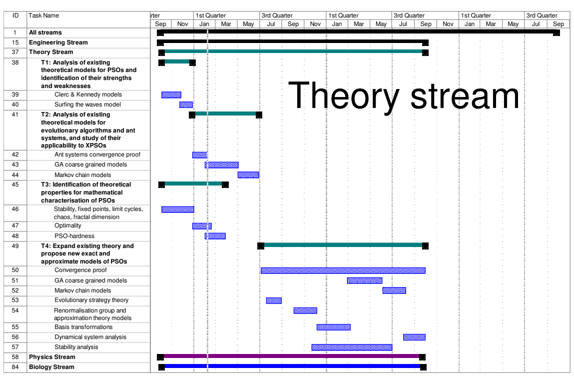
- **STAGE T3** (6 months, in parallel with T1 and T2)
  – Identify the key properties for the mathematical characterisation of XPSs (fixed points, limit cycles, stability, convergence, complexity, chaos, fractality, randomness, attractors and basins of attraction, phase transitions, …).
  – Optimality and XPS-hardness measures, measures for the exploitation of fitness landscape features such as gradients and curvatures.

Theory Stream

- **STAGE T4** (15 months)
  - Expand and apply some of the techniques explored in Stages T1 and T2 to the study of XPSs.
  - Develop new exact and approximate models of XPSs based on basis transformations (Walsh, Fourier, etc.), projections (e.g. principal component analysis), embeddings, the renormalisation group and approximation theory models (e.g. Taylor expansion), etc.
  - Identification of qualitatively (and quantitatively) similar behaviours of XPSs, a stability analysis and a convergence proof.

Physics Stream

- **STAGE P2** (9 months)
  - Investigate the consequences of allowing a richer physics for the particles themselves (e.g. particles with different mass, momentum, or volume, directional attributes such as spin, dipoles)
  - Many body dynamics approach:
    - classical at zero temperature,
    - quantum mechanical at zero temperature,
    - classical at finite temperature,
    - quantum at finite temperature.



Physics Stream

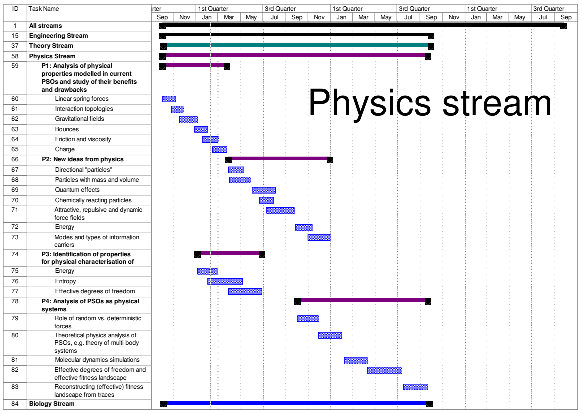
- **STAGE P3** (6 months, in parallel with P1 and, partly, P2) Identify and explore suitable properties for the physical characterisation of XPSs, such as energy, entropy, effective degrees of freedom (e.g. effective temperature) etc.

Physics Stream

- **STAGE P1** (6 months)
  - Analyse the properties (e.g. position, velocity, momentum, gravitational fields, bounces, friction, viscosity, and charge) and interactions (e.g. linear spring forces, full or linear interaction topologies) modelled in current PSOs, and
  - study their characteristics from a physics-based, classical-mechanics point of view

Physics Stream

- **STAGE P4** (12 months, partly in parallel with P2) use the analysis tools available in physics to study XPSs as if they were real physical systems.
  - theory of multi-body systems,
  - mean field theory,
  - effective degrees of freedom (and effective fitness landscapes), and
  - molecular dynamics simulations.



Biology stream

- **STAGE B3** (9 months) construct quantitative models of the key behaviours, and of the bodily, cognitive, and environmental features identified in B1 and B2.
- Include models of individual join-stay-leave decision making.
- identify biologically relevant characteristics for the classification of XPSs thereby contributing to the creation of the XPS periodic table.

Biology stream

- **STAGE B1** (6 months) In nature, flocks and swarms are much more varied, flexible, and responsive than the simple aggregations used in basic PSO.
  - Identify *the key behaviours in natural flocks and swarms* and the problems solved by them.
  - Areas investigated will include: fish schooling, bird flocking, food foraging, division of labour, aging, energy, food, symbiosis, altruism, reaction to threats, death, reproduction, and heterogeneity.

Biology stream

- **STAGE B4** (6 months) interpret the simulation results with biologically realistic XPSs with the objective of tying them to the functionality and behaviour of biological swarms.
- identify the mathematical models of PSOs developed in the theory stream which appear most appropriate for application in biology,
- a preliminary adaptation and testing of such models in biological contexts.

Biology stream

- **STAGE B2** (6 months, partly overlapping with B3) identification of the key cognitive, bodily, and environmental features necessary to support a variety of task achieving biological swarm behaviours.
- Cognitive abilities: active and passive perception and proprioception, communication, memory, decision procedures, and the exploitation of internal models.
- Bodily characteristics: shape, effectors, motor abilities, and capacity for action.
- Environmental characteristics: affordances for stigmergy, affordances for signalling and communication, and for motion and action.