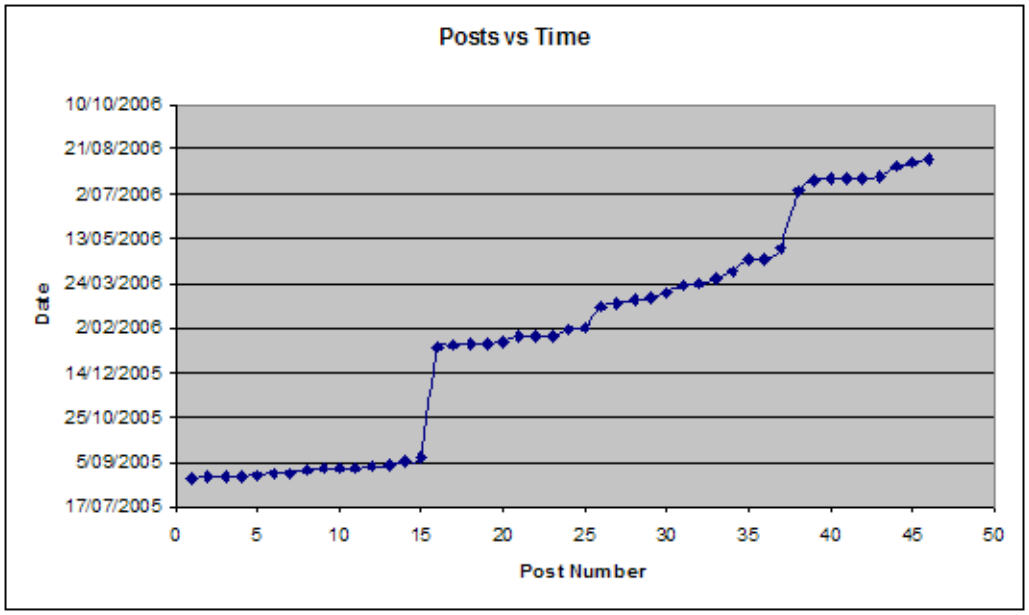
Pensive Pondering Posts

This document contains all blog posts from my former blog '*Pensive Pondering*' that was online from August 2005 to approximately September 2006 at the URL http://pensive-pondering.blogspot.com. This document was created from the first version of posts emailed to myself via the post notification feature of blogger during that time. Posts are left in their original form without changes to spelling, gramma, or formatting. Comments were not included, and some posts were updated after their initial posting, the changes of which are not captured in this document.

- *Jason Brownlee, November 2007*

Totalling 46 posts over approximately 12 months.



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General purpose optimisers are IMPOSSIBLE!

18th August 2005

Optimisation is search. Given a cost function *f*, locate an extrema of interest of that function (minima or maxima). Simple enough and well understood, moreover many problems can be defined as an optimisation and thus as a search problem.

In my work I concern myself with strategies for optimisation, and the strategies that I am interested in were devised inspired by biological systems. In some circles these algorithms, these procedures, these search strategies are called metaheuristics. I really dislike the term metaheuristics (subject for a future rant) so I am going to talk about strategies. The specific strategies I concern myself with are evolutionary algorithms, ant-colony optimisation algorithms, particle-swarm optimisation algorithms, artificial immune system algorithms, and so on.

These search strategies sample a problem-specific search space or solution space and provide approximately optimal solutions efficiently. The algorithms use randomness (pseudo-randomness), though are directed. Thus, rather than being deterministic, they are probabilistic search procedures. Specifically they employ the Monte Carlo method (MC) rather than a Las Vegas (LV) approach. The difference is that MC will use constant efficiency with no efficacy guarantees, where as LV will locate an optimal solution, though without efficiency guarantees.

Now that all the introduction is out of the way what I really want to get to is a specific well known and widely misunderstood impossibility theory in search and optimisation. This theorem is called the "***no free lunch***" (NFL) theorem, and although I am still coming to grips with intricacies and implications I felt the need to rant by current thoughts.

Some good resources to get stuck into the theorem are here, here and here. The seminal work was a technical report "No Free Lunch Theorems for Search" (1995) by Wolpert and Macready, which was later written up in transactions on evolutionary computation "No free lunch theorems for optimization" (1997). Wikipedia also has a brief introduction here.

First, I wanted to lay or draw attention to the key points of this theorem:

*When searching for an extremum of a cost function, **ALL** algorithms perform the **SAME** when averaged over all possible cost functions. This applies to **ANY** performance measure.*

Get that? I will say it again a few different ways so that it really sinks in.

There is no such thing as a general-purpose black box algorithm; in fact, it is theoretically impossible. If algorithm A outperform algorithm B on some set of cost functions, then there will some other set of cost functions for which algorithm B will outperform algorithm A.

It is a theory and there are caveats when you start trying to apply the idea to the real world. The theory assumes cost functions have a uniform prior probability distribution – that the algorithm assumes nothing about the problem, which is not realistic. Further, empirical evidence from many works shows us that in the real world problems, we are interested in (a subset of all possible cost functions), the algorithms we apply do better than random search and directed random search.

The theorem applies to deterministic and stochastic search algorithms. It applies to algorithms that do learning and algorithms that adapt their strategy as they search. In fact, the geometric proof indicates that the observed behaviour of a strategy on a cost function provides no justification for predicting its future behaviour on the cost function (doing well does not mean it will continue to do so).

Wolpert and Macready indicate that we (the practitioners) should be interested in the match up between algorithm a and cost function f. They highlight that the practitioner should be weary about generalising results – and this clearly applies not only between problem instances, but also problem classes. Here's a quote I really like:

"*The comparisons reporting the performance of a particular algorithm with a particular parameter setting on a few samples problems are of limited utility.*"

That is putting it nicely.

It is all about matching algorithms to functions. A part (perhaps a larger part) of our (the practitioners) job is to find and promote these mappings. The idea of a priori knowledge should not be a dirty word (as it is in EC), in fact, NFL tells us that if we do not use any a priori knowledge then we may as well use random search. I could go on about this forever – I will leave on this simple note: Stop trying to build general problem solvers and pay attention to the lessons of "no free lunch".

Metaheuristics!?!

19th August 2005

Back in the old GOFAI days, a heuristic was a 'rule of thumb'. It was some useful (typically problem specific) piece of information that ***provided some sort of short-cut in the search space***. We are talking about the old informed shortest-path graph searching algorithms like A*, best-first and Dijkstra. The origin of the word is Greek and means "I find" or "I discover" – Eureka. Therefore, heuristics are formal and helpful rules when searching.

Problem specific heuristics are easy to grasp. In best-first or A*, a heuristic may be to minimise the estimated distance or travel time to the goal when selecting the next node to move to. In the TSP, a heuristic may be to include short length edges (nearest neighbours) in an attempt to minimise overall tour length. In this sense, heuristics are problem specific or a priori information about the problem that provide a best guess or first guess approach to getting a solution. The problem is that for hard problems heuristics can lead to suboptimal solutions, thus following a heuristic alone can and is (in the hard problems we investigate) is problematic.

Enter *meta*heuristic. The definition of the term is problematic, though its use is prolific in the swarm intelligence fraternity (see the metaheuristics network), and is seeping into other fields like EA. Some canonical examples of metaheuristics are ACO, PSO, EA, Tabu search, iterated local search, and SA. Before getting into what I think the term means, I'll provide some definitions from the field.

Perhaps the best introduction to the term I've come across is Blum and Roli's paper "Metaheuristics in Combinatorial Optimization: Overview and Conceptual Comparison" (2003). This paper is also sighted on Wikipedia's definition of term.

Firstly, it is commonly accepted that metaheuristics are applied to combinatorial optimisation problems. This is compatible with the above listed algorithms – in fact the vast majority (all?) of optimisation on digital computers is discrete (thus combinatorial). Most data types practitioners use for so called "continuous function optimisation" consist of a discrete set of 2^32 to 2^64 numbers.

Here are some clips:

"*[metaheuristics] combine basic heuristic methods in **higher level frameworks** aimed at efficiently and effectively exploring a search space*"
- Blum and Roli (2003)

"***iterative generation process** which guides a subordinate heuristic by combining intelligently different*

concepts for exploring and exploiting the search space"
- Osman and Laporte (1996)

"*The subordinate heuristics may be high (or low) level procedures, a simple local search, or just a construction method.*"
- Vob et all (1999)

"*high-level strategies which guide an underlying, more problem specific heuristic, to increase their performance.*"
- Stützle (1999)

If you want to get really confused, check this one by Dorigo and Stützle in "Ant Colony Optimization".

"*... a metaheuristic can be seen as a general-purpose heuristic method designed to guide an underlying problem-specific heuristic [...] toward promising regions of the search space ...*"

Too many 'heuristics'!

The quote that really bothers me in the context of "**no free lunch**" is this one from the same page:

"*A metaheuristic is therefore a general algorithmic framework which can be applied to different optimization problems with relative few modifications to make them adapted to a specific problem.*"

Ok to summarise we are talking about a high-level framework, iterative, with or without a population and with or without a problem-specific heuristic (in the GOFAI sense). They are typically stochastic (read probabilistic) rather than deterministic, typically include mechanisms for not getting stuck in local optima, typically include a memory and typically employ a local search at the end of the run to refine results.

From my perspective, I like to use the term "search strategy" or just strategy. Metaheuristics describe search strategies – and this is the commonly accepted definition. I would like to make a few observations. It seems that there are metaheuristics and then there are metaheuristics. What I mean is, there are algorithms like ACO that use problem specific 'rules of thumb' to direct the search to areas of expected pay-off and randomness to find the "sweet spot" in the area, then finally a local search to get a highly-tuned result. This fits my understanding of a high-level ***meta***heuristic – a strategy that pieces all these things together to get a better overall result.

An EA or SA or even PSO, conventionally (we are talking canonical definitions here), they use less problem

specific information – just enough to get the search working (representational issues). They use history alone, and in practice are followed up with a local search. Does this mean that an EA strategy (crossover and mutation) or a PSO strategy (particle position and velocity in Euclidean space) are heuristics? Does it imply that as information (samples / history) is collected through experience with the search space, that the exploitation of this **problem-specific** information in the search (something that all of these metaheuristics do) is called a heuristic as well?

This is pedantic I know and has no real impact. Perhaps its just philosophy. A metaheuristic is a search strategy; the question is: is it really any more than a search strategy?

The Philosophy of Genetic Algorithms for Architectural Design

20th August 2005

I came across an interesting article via a post on the IlliGAL blog. The article was written by Manuel De Landa titled "*Deleuze and the Use of Genetic Algorithm in Architecture*" (2001). The article is available in rtf and html here and here, and has been presented by De Landa a number of times.

It is an article (not a paper) and its focus was philosophy, so I will not bring the scientific smack down. The crux of the article is highlighting the imperative of suitable representation when using an evolutionary process for design - specifically in the context of interactive evolutionary computation. A good but well understood point, at least in the field.

Manuel De Landa is contemporary Mexican philosopher who currently teaches at Columbia University School of Architecture in New York. There is a Wikipedia article on him, which further references annotated bibliographies here and here. De Landa is into work by the late French philosophiser Gilles Deleuze, and in this work draws upon what De Landa refers to as Deleuze's philosophy of genesis of form. I do not know philosophy, so I cannot comment I this inspiration and adaptation, though I am interested in commenting on the ideas as they apply to GA's.

De Landa discusses Deleuze's genesis of form in another article "Deleuze and the Genesis of Form" (1997), which is a little lofty and esoteric (philosophy) for me. The three points De Landa focuses on what he refers to as three forms of philosophical thinking which were drawn together by Deleuze, as follows:

- **Populational Thinking** – The idea of looking at the population as the evolutionary unit, not the individual. This is intuitive for practitioners of EA's I would think.
- **Intensive Thinking** – The idea of having a sufficient "genetic" vocabulary to describe what it is you are working towards as well as enforcing validity of results (ultimately constraint satisfaction).
- **Topological Thinking** – Topological in the mathematical sense – specifically abstraction and patterns that are invariant to deformations. Specifically, what De Landa refers to as 'abstract diagrams" and the more common term "body plans" from morphogenesis and embryogenesis.

The GA focus of De Landa was architecture – specifically the idea and issues raised when using an interactive evolutionary process to "design" buildings. His focus was on applications these techniques may have as aids in artistic design – and artistic critique requires human input. As such, he specifies the representation needs to be sufficiently rich to surprise or shock the observer. I guess I can bend to this somewhat – if the practitioner knew what they were after they would just design the building by hand or dictate the design to an architect.

The focus on intensive thinking was concerned with the validity of builds proposed by the process before a human critique could be given. In practicality I would assume this – though not knowing architecture intimately I cannot comment on the difficulty or detailed related to doing this. Surely, it could be broken

down to a set of physical constraints that could be tested or simulated on a proposed model (a ‘does the building work’ function).

I do like De Landa’s thoughts on the role of the human designer. Specifically that it is a different type of creativity similar to a dog breeder breeding a prize dog, or a prize racehorse breeder, the idea of selectively “sculpting” a design. Again, these are familiar ideas.

Practitioners of EA’s are familiar with thinking in terms of populations as mentioned, and De Landa does mention the problem of premature convergence. Topological thinking should also be either familiar or attractive to any old salt EA practitioner given its relationship with genetics and its conceptual simplicity and relation to the so called solution ‘genotype-phenotype’ encoding we perform. De Landa does ultimately hit the right points and problems related to interactive design, although with a philosophical air, and I did enjoy seeing a demonstration of a useful grasp of mathematic topology given the abuse computer science gives the term. If you into interactive EA’s and feel like an interning, if not philosophical discussion on the problems of representation and encoding, I recommend a read.

Genetic algorithms are NOT function optimizers

20th August 2005

Kenneth De Jong is old school Evolutionary Computation (EC), when the only vocabulary you needed was GA. His 1975 dissertation is available online here at the George Mason ECLab, and his contributions to the field of EC are immense.

I recently came across an interesting paper by De Jong titled "Genetic algorithms are NOT function optimizers", published in the Proceedings of the Second Workshop on Foundations of Genetic Algorithms (1992).

It is an old foundational paper (obviously), and is well worth a read by any EC enthusiast. Essentially the crux of the paper is that genetic algorithms are all about how to **allocate a finite set of decisions such to maximise the cumulative payoff in the face of uncertainty**, and they must be adjusted to do optimisation problems. "Ouch!" or "Huh!" I hear you say (or read?). Yeah – now let me let De Jong tell you why.

It seems what ticked De Jong off back then was that GA's were becoming synonymous with optimisation, and De Jong wanted to highlight the fact optimisation is **one** of the things that GA's can do – it is not what they are. He highlights the fact that John Holland's initial work on GA's was the development of *robust adaptive systems* motivated by elements of biological evolution. The takeaway point is that this robustness and adaptiveness can be exploited in optimisation problems, but this is nothing more than a specific application of the 'technology' that resulted from Holland's dangerous idea (contemporary reference intentional).

Something that I really do like is the acknowledgement that the inception of the "GA" was the development of a system without explicit use – that ultimately in this case the tool came before the problem ("cart before horse" as De Jong indicates), rather than the problem dictating the development of a tool. My observation is that this is what many practitioners want to do in this field (biologically-inspired computation), though feel guilty for admitting it or inhibited to do it. Why? It's too much invention and not enough engineering. What a shame I say, science is about discovery with rigor, which can include invention (can't it?). I want to find more on this idea I think.

De Jong indicates that optimisation is essentially only concerned with efficacy and efficiency (which is quite fair), and these are poor or incomplete measures by which to investigate the behaviour of a genetic algorithm. This leads into a (what is now boilerplate) point about schema theorem (building blocks) being a better investigatory approach. Specifically, a GA can be viewed as optimising a sequential decision process involving uncertainty, and that rather than the general efficacy and efficiency metrics, we can use the more useful (to the technique) exploration and exploitation of payoff to analyse GA behaviour.

The current population of evolved candidate solutions represents the current focus of the search – conceptually and literarily this is something I always refer to, an De Jong also makes reference to the analogy. He goes on to mention that the canonical GA does not maintain the best solution by default as is required by an optimisation algorithm that is only interested in bottom line. This is given as the point that lead to practitioners adding elitism. De Jong then raises the concern as to the effect that modifications like this to make a GA more 'optimisation like' have on the underlying strategy. He further points out the scaling

issues with GA, in that they are effective at finding the general region of an optimum, but are poor at locating the locally best result (thus practitioners use a hill climber to finish the search). He indicates that this behaviour makes sense from a 'maximising cumulative returns' point of view (it is easy to make big moves), rather than an optimisation point of view.

There are further points related to representational concerns, problem specialisation and misconceptions of GA's, and I don't think they are as helpful to the case. The title of the paper was and still is shocking as intended, and although the arguments were subtle at best, the general aim of 'getting optimiser-focused GA practitioners to think of the bigger picture' is met. A genetic algorithm is NOT a function optimiser, although it can do function optimisation. Regardless of how the tool is analysed or how it works, if a practitioner is interested in function optimisation and uses something (a GA for example) that does function optimisation, then within that scope, surely it IS a function optimiser.

Pondering Pessimism

22nd August 2005

Wow, Goldberg found my blog, and had something to say about my current content. If you read this Professor Goldberg - thankyou, and thanks for the attention you have drawn to my little space. (BTW, I do subscribe to your ideas of "little models" - it just sits right for me, not only with EA's, but with complex systems analysis).

For me, this space has the dual intent of first ***capturing my thoughts*** on interesting papers, and secondly ***getting outside feedback*** (my group) on my interpretations. When one of the old school GA movers-and-shakers says that I am pessimistic and perhaps I'm misallocating my resources - I pay attention, and then some. As it happens, I thought (used to anyway) that my writing was pretty optimistic. I guess the topics of some of my selected papers could be seen as pessimistic - though I don't think emotion is enough of a reason for me to ignore work.

To me, NFL and De Jong's article (GAFO) were not trivial or uninteresting, quite the opposite, and this was the reason I felt the need to pseudo-review and rant on these topics. Being new and wanting to contribute to the field, I think it is my duty to gain a rounded view to be able to useful analyse, criticize, and scope novelty. I am passionate about biologically inspired computation, it is my world right now, and I expect it to be until I complete my dissertation. However, I need to reconcile work like NFL and GAFO - I personally need to do more than acknowledge their existence, I need to integrate the findings into my evolving understanding of "the field". By no means am I intentionally indicating scientific investigation into evolutionary computation is misdirected, on the contrary I hope I am evangelising a broader view of the field.

I got some questions with the attention gained after the post on the IlliGAL blog. (which I have been an avid reader of since its inception). The RSS feed for subscription is here (for future reference, see the link at the bottom of the page). I do not talk about work too close to my own research for fear of being ripped off - a real shame if you ask me, but centre policy. I am currently working towards a paper, and once it's out - my rants will be on topics far closer to my work. Oh yeah, I'm not predominantly researching EC. As I've alluded to I'm broadly a biologically inspired computation (BIC) guy, with tendrils in artificial immune systems (AIS) or perhaps parallel evolutionary algorithms (PEA's) depending on the way I play my cards.

Art as Optimisation

24th August 2005

Here is a bit of fun. A work on **TSP Art** recently surfaced on my "*to-read*" paper stack - I remember first seeing mention of this on CleverCS (site is temporally down) about a month ago.

Continuous line drawing is a style of drawing where you place the tip of the drawing implement on the paper, and do not remove or lift the implement until the drawing is complete. In a research letter titled "Continuous line drawings via the travelling salesman problem" Operations research letters (2004), Bosch and Herman provide a procedure for reducing a given image to a TSP problem that when solved provides a guide for computer-based continuous line drawing.

The Bosch and Herman procedure is as follows:

1. Given an image, convert to greyscale
2. Discreterise the image into larger than pixel squares (say 4x4) and calculate the mean greyscale value for each square
3. Rescale the mean values to between zero and a user selected maximum number of cities per square
4. Place the number of cities specified in each square using a uniform probability distribution for x,y position
5. Solve the TSP using the Concorde TSP solving package

Even with higher maximum cities per square values, the images are reminiscent of the original if you squint, though they are not great. Kaplan and Bosh indicate the problems with the technique in their paper "TSP Art" (to appear in proceedings of BRIDGES - Mathematical Connections in Art, Music, and Science) are centred around the process around distributing the points (cities) on the original image. In their work, they propose to distribute cities in a square as to approximate the tone of the source image. Reference is made to the halftone technique used for images in newsprint media, as well as a stippling artistic technique used to simulate shading.

Kaplan and Bosh demonstrate the effects of a number of point placement algorithms that incorporate more image specific information such as a simple grid-based method, a weighted Voronoi stippling method and ordered dithering (fixed pattern) methods. Further, tests with adjustments image contrast were also performed which produced less 'busy' final renderings. Two rendering methods for the optimised tour were also demonstrated. The first used the cities as control points for a B-spline curve to remove the sharp edges of the tour, and the second used the local density of the Voronoi region to control the line thickness. The resulting images do look aesthetically interesting, especially from a distance or when squinting (reminds me of the old magic eye when I was younger).

Kaplan and Bosh mention that the problem involves optimisation at two levels. The first in approximating the original image (defining the TSP), and the second as the solving of the devised TSP. They mention and that the first has a strong affect on the aesthetic result of the second. What I like is the mention of the relation of geometric optimally (or lack thereof) to aesthetic quality. They mention that nearest neighbour connections are more important that global optimality for the aesthetic quality of the image - given the density of points provided by stippling.

A Google search reveals a mention (2004) of the research letter in the Oberlin alumni magazine. A gallery of TSP art is available online here. Professor Bosh has a website that other related algorithmic art such as images devised from a domino placement algorithm. The Mathematical Association of America (MAA) also has a mention of the work here.

Academia and open source programming

24th August 2005

Langford and Pool have recently blogged on the similarities and dissimilarities of academia and open source projects on the Machine Learning (theory) blog. The post is also currently mentioned on smart mobs. Given my (perhaps limited) participation and exposure to both circles, the points mentioned sit well with me, particularly point four of the dissimilarities (academics perhaps not making effective use of available technologies). A point about opensource that I have always found very attractive is the idea of ***release early and release often*** as taken (here) from the famous "The Cathedral and the Bazaar". I do not think we can do this effectively in academia (perhaps we do not want to do this), and this sometimes frustrates me. The conventional way of getting feedback on personal ideals (illusions?) of novelty to run the work by geographically local and trusted peers and perhaps fire off the odd email to trusted correspondents. Ultimately, the best process we have for getting broader feedback on early work are conferences - which work, but which still have a long lead time compared to opensource that can comment anywhere and anytime about their ideas and work. We have alternate formalisms like research consortiums, and symposiums to present early research, posters, technical reports, and so on.

We have the formal tools and processes (mentioned above) and they work, though it is still taboo to use less formal tools and processes, to email, instant message, or blog about early research, or wild research ideas for fear of being ripped off and losing the illusive yet required element of novelty. I imagine the potential speed of innovation (or at the very least the potential speed of refinement) if I could blog (informal communication medium) about my current ponderings on work that will eventually become by thesis. I am talking about mass and informal peer review. It may be timely (if there is an audience for such a thing), though the problem is that by its very nature it is ad hoc in that there are no peer review guarantees like there are with more formal processes. Further, there are going to be issues with contribution, acknowledgement, and ultimately ownership if such feedback is ever attempted to be integrated into more formal processes. Alas, I/we are left to blog about published (safe) works and ideas on the fringe of the central area of interest. Thoughts?

I have two other interesting little tidbits for the end of the day, well the end of the day where I am anyway. The first (here) is a post on Computational Complexity about the selection of a research area by a student being analogous to simulated annealing - I like this idea, it is simple and it is useful. The second is a journal article by Krimbas titled "On Fitness" (on SpringerLink) in the journal of Biology and Philosophy (2004). As the title of the journal indicates, the article is on the philosophy of the conceptualisation of fitness in the context of population genetics. It goes through the history of the term, the formalism of a definition for such a conceptualisation, and failure of existing definitions to fit the proposed formalism. I used to read books on population ecology and such when I got into niching GA's (last year) and so I found the article interesting, though for an algorithmic purist that is trying hard to depart from metaphors and inspirational nomenclature (my current aspirations), it may be less than relevant.

Negative Selection - Modelling in the complement space

27th August 2005

Negative selection in the context of the immune system (not the contect of population genetics or politics) refers to the process used to prepare T lymphocyte cells in the thymus. I do not want to get bogged down on biological terminology so I will provide a simple abstracted description. The system is a classification system that uses detectors on observed patterns, and employs many (millions) autonomous and immutable discrete detector units. These detector units are generated and released from a specific detector-factory through a process called negative selection. The process starts by randomly generating a number of potential detectors. The detectors are exposed to pool of positive (or good) samples (exemplars), and those detectors that react (that are stimulated significantly) are removed, and those that remain are kept and employed in the classification task.

There are two ideas presented here, the first is *modelling a classification in the complement space* (lets stick with binary classification), and the second (negative selection) is process which can be used to *prepare atomic and immutable detectors* for this form of classification. Both broad ideas have been borrowed from the mammalian acquired immune system, and are the predominant ideas used in the field of artificial immune systems.

A third related and useful idea is that of *maturing the detector system over time* (learning), in a process that is based on the clonal selection theory in acquired immune system. Again, the description will keep a distance form biology. When a detector that is in use (in its classificatory capacity) is sufficiently stimulated, it proliferates producing many similar detectors in an effort to improve stimulation and thus detector within the system in the future. Further, the same negative selection preparation process is applied to initialise the cloned detectors.

To me at least, these are very interesting ideas, and I recommend "Artificial Immune Systems - A new computational intelligence approach" (2002) by de Castro and Timmis, to anyone seeking more information.

These ideas have been successfully applied to novelty detection systems like network intrusion detection [phd dissertation] (1999), change detection (1997), financial fraud detection (2003), refrigerator fault detection (2003) and other security related problems. What bothers me is that for all the attractiveness of these simple ideas, the fact that these binary classification problems are modelled in the complement space alone (at least in the works in the field on the topic).

The domains these ideas are applied to have common characteristics.

- They are online, and the system must specialise over time to the patterns in the data stream.
- The volume of good patterns out weighs the volume of bad patterns in terms of observed data.
- The observed distinct patterns that are valid outnumber the number of distinct patterns that are invalid.
- The size of the distnct valid pattern space is small in comparison to the size of its complement.

With complete prior knowledge, modelling the complement space for classification would be the most efficient, and to me, it seems that the goal of the system is to approximate this approach by learning the

observed complement patterns. Conceptually this is the same to me as building and using a virus library in antivirus software or a black list of spammers at the same time as using algorithms to detect (guess) at new viruses or spammer addresses. An old and pervasive idea in information technology.

Approximation may be efficient, but when false negatives can mean that the network or host has been infiltrated, I question the use of modelling the complement alone. In fact, the efficacy of the system is only going to be as good as the random or neighbourhood guessing for new complement patterns, or as mature as the library of confirmed - observed complement patterns. It seems negligent not to use some kind of confidence measure that the pattern is not normal by using some additional model of what is normal. I am sure that many security produces would use this approach - difference from normal and similarity to not normal, rather than just the latter as proposed by the artificial immune based systems. This does seem logical to me, though the biological system does not do this. Perhaps for efficiency over efficacy reasons (efficacy in numbers or in diversity of systems across a population), or perhaps for molecular bonding reasons, the biological acquired immune system models the problem of detecting and combating invading pathogenic material in the complement space. Interesting. Here is a Google Answers question I posted back in April on the same theme.

Here is what I really love about the idea of negative selection, and if I had the time (I may still make the time) I'd be getting inside this idea: ***I don't know what I want, but I know what I don't want***. This is a specialisation of negative filtering and ultimately of negative selection.

This is really an idea of preferences, and has been used as the basis of online negative databases (2004) like adaptive radio paper (2005), and could be used for collaborative preference or recommended systems (2002) based on the acquired immune system. Between you and me, this is a powerful idea and could be the basis of the next large-scale, community based, collaborative, (web 2.0) platform. (or not).

I Like PEAs

29th August 2005

That is ***Parallel Evolutionary Algorithms*** or PEA's (see EA as a starting point). I recently came across an excellent review journal article on PEAs on IEEE explore titled "Parallelism and Evolutionary Algorithms" (2002) by Alba and Tomassini. There are many review articles on the topic, and many of them are very good, but this paper is current in particular made some points that I had been thinking about recently.

Interesting points and points I liked the most from the paper:

The recognition and promotion of the benefits of parallel EA's (islands) with or without parallel hardware. The highlight that point that a partitioned population will usually run faster (I assume convergence time) than a panmictic EA. (You could make the argument that niching coupled with speciation attempts to address this whilst using a single population of candidate solutions)

They provide a rudimentary three dimensional plot of parallel EA's with the following axies labels; number of sub-populations, amount of interaction, subpopulation size. They then proceed to very briefly indicate the relations between approaches like cellular EA, island EA and panmictic EA. Simple and effective.

The identification of Internet based EA's and the point that they need more research attention. Large ad hoc networks of heterogeneous computers. The use of platform-independent programming languages like Java, the use of language-independent technologies like XML and the use of robust architectures like P2P.

Accepted (perhaps suggested common usage) configuration approaches such as using a ring (island connection) network topology and using moderated frequency, low magnitude best-individual or random-individual migration. The point that simply running parallel EA's is not as effective as running parallel EA's that facilitate information sharing (migration).

Finally, the paper provided an excellent source of references of the topic.

The paper is presented with a strong separation of algorithmic models (ideas) and algorithmic implementations (hardware and technologies) (as was indicated and intended by the authors). Further, the review of distributed technologies (sockets, message passing and such) used in parallel EA's was something I'd not seen mentioned in PEA literature before - kind of assumed, but still useful. My take away points were the push towards hybrid approaches both in terms of hybrid parallel EA's and hybrids with other search strategies, as well as the need for further work on EA's for heterogeneous network architectures like the Internet, and P2P.

DREAM and Epidemic-Inspired Migration

30th August 2005

The DREAM Project (Distributed Resource Evolutionary Algorithm Machine) was a research initiative by the European Commission Information Society Technologies Programme (Universal Information Ecosystems) to develop a *open* and *scalable* framework for the automatic distribution of evolutionary algorithms. The project was backed by a three year grant that ran out at the end of February 2003. evoweb has a good project overview here. The first paper on the project was "A Distributed Resource Evolutionary Algorithm Machine (DREAM)" (2000) in IEEE, and a good overview of the project can be found in "A Framework for Distributed Evolutionary Algorithms" (2002) in PPSN VII. A collection of papers on DREAM is available on from the main project website here.

The first point I like about the project was the aim to unify existing evolutionary algorithms such that solutions to optimisation problems can be evolved using a number of complementary mechanisms. I do believe that hybridisation, not only of evolutionary algorithms is the way forward for the real world practitioner.

The second point I want to mention is that admirable and ambitious project goal to permit users access to the technology at five varied stages, from the highest level of CPU donation and GUI-based problem definition, to the lowest level technology substrate exploitation. This makes the technology accessible, flexible, marketable, and coupled with the aim of unifying EC, I am impressed by the vision of the project. See here for a concise description of the five classes of system users.

The final point I want to discuss was the hook that made me take a closer look into this project. Specifically I am referring to the targeting of wide-area networks of unreliable links and heterogeneous computers (the internet) and the use of a peer-to-peer substrate to distribute the system. This lower level of the DREAM project was referred to as DRM - the Distributed Resource Machine which was inspired by epidemic algorithms, more commonly referred to as *gossip-based* or *rumour-based* broadcast strategies in the P2P obsessed literature.

The DRM is described as a P2P overlay network or autonomous agent environment, not limited to EC. It is indicated that templates can be implemented on top of this substrate, such as the familiar island population EC approaches. The distributed resource system is server-less (consists only of peers or nodes). It uses an epidemic algorithm broadcast strategy, and a peer neighbourhood management system that exploits the gossipy nature of communication. For further (though still too vague for me) description of the DRM see "A Scalable and Robust Framework for Distributed Applications" (2002), and "Maintaining Connectivity in a Scalable and Robust Distributed Environment" (2002).

The now pervasive ideas of gossip-based broadcast seem to stem from a seminal work from the Xerox Palo Alto Research Centre (PARC) titled "Epidemic algorithms for replicated database maintenance" (1987). The premise behind this work was the investigation of randomised alternatives to complex deterministic database replication schemes. Inspiration was taken from mathematical models of epidemiology, and three approaches were proposed and analysed; *direct mail*, *ani-entropy* and *rumour mongering*. In particular the rumour mongering approach consisted of ignorant sites that would pass-along hot rumours (new updates) to randomly selected neighbours. Once a sufficient number of neighbours indicated they had already received

the rumour, it was no longer propagated by the site. The approach was shown to trade off strong reliability guarantees for high scalability, demonstrating that the system was rapidly driven towards a state of mutual data consistency, even with non-uniform spatial distributions.

Gossip-based broadcast systems work, though there remained a scalability problem in regard to each nodes view of the system. A work titled "Lightweight Probabilistic Broadcast" (2001) proposed random sub-set views of the system or neighbourhoods to address this problem. The approach was called *lpbcast* where randomised views constantly evolved overtime based additional connectivity information provided with gossip messages received. DRM exploited this idea and extended by giving each node a long-term memory to overcome re-connectivity problems when subsets of the system are separated from the network for an extended period of time (sounds like tools for building small-world networks to me).

As was discussed in a previous post here, effectively exploiting internet based resources is an exciting area of research for evolutionary computation. Although the work on the DREAM project was from 2000-2003 (a few years ago now), the ideas were right for the time (not just jumping on the P2P bandwagon) - and this is still an area of EC that needs further attention! By thinking in terms of gossip, rumours, and epidemics, perhaps we (as a field) can devise entirely new population structures and migration strategies (fundamental technologies) for truly large-scale collaborative optimisation tasks.

Academic Social Bookmarking

30th August 2005

I came across a Nature editorial (via smart mobs) titled "Join the social revolution" on the utility of collaborative bookmarking (for papers) in academia. The article mentions del.icio.us, citeUlike and the new Nature backed solution called Connotea. I have been using del.icio.us for months and swear by it to keep track of invaluable research web resources. The take away point for me from the unashamed self-promotion for Nature's new service is that collaborative bookmarking solutions built from the ground up for research (for capturing academic papers), may be a better option than a generic solution like del.icio.us. Specifically, features like automatically capturing bibliographic information in when a resource is "remembered" into the system would be very handy indeed.

Negative Preferences with an Information Immune System

1st September 2005

The term *information immune system* (IIS) was first coined by Neil Postman at a talk to the German Informatics Society titled "Informing Ourselves to Death" (1990) to describe the use of technologies we employ to filter our ever-increasing flood of information, that inevitable fail - adding even more information to the flood. Chao and Forrest use the term to describe an information filter that uses negative preferences, inspired by the natural immune system.

In a paper titled "Information Immune Systems" (2003), Chao and Forrest describe a filtering system that eliminates undesirable information before it reaches the user. Instead of bringing interesting information to the attention of the user (as in canonical collaborative filtering), the system quietly censors unwanted data. The system is trained by the user who acts as a mediator on a stream of information provide by the system. Negative feedback is captured from the user, and a user profile is built up over time. Similarities are drawn to the acquired immune system, which uses conceptually a similar approach to detect and learn to better detect a host organism from a continuous stream of pathogenic material.

For each negative preference the user indicates, the system creates a negative detector (exemplar). The information stream is then filtered (compared against) the users prepared negative detectors for similarity; any information that is matched by the detectors is removed from the stream. This is reminiscent of case-based reasoning, in particular what is called "lazy learning" (see Instance-Based Learning Algorithms 1991). The user the provides negative feedback (negatively selects) information that makes it passed the filter, thus improving the quality of the filter over time. The system (thus the a suitable representation) assumes neighbourhood relations between data points in the information stream, such that points that are spatially "near" (spatially close to using a domain-specific similarity measure) rejected data points are also rejected. This assumption permits detectors to cover crisp or fuzzy regions of the data search space, or what Chao and Forrest refer to as the "*information space*" as opposed to the "*shape-space*" used to describe matching between antibodies and antigens.

Given the exemplar basis to the system, the work highlights that it is amenable to combining multiple users profiles facilitating collaboration of negative preferences. Solutions that make it through the union of each users set of negative detectors are referred to as "*consensus solutions*". The work proposes that the system provides an alternative approach to navigating a parameter search space, where the system randomly samples "*implicitly accepted*" candidate solutions, and the negative detectors constrain the sampling process to areas of non-interest. The proposed information immune system (IIS) was prototyped and demonstrated in an interactive aesthetic preference system and a group-based negative preference adaptive radio system.

An aesthetic based negative preference system was proposed by Chao and Forrest in "Generating Biomorphs with an Aesthetic Immune System" (2002). The system was centred on the generation of biomorph images, originally proposed by Dawkins in his 1986 book "The Blind Watchmaker" as an evolutionary art experiment (see here for an example Biomorph applet). Each user was exposed to a stream of biomorph images, and provided negative feedback to the system on the aesthetics of each image. It was a successful demonstration of the conceptualised information immune system (IIS) for single users negative preferences, though showed poor results when multiple user preferences were combined. This was blamed on the lack of aesthetics in the similarity function used between biomorph solutions, and user's disparate subjective aesthetic tastes. It was

demonstrated that an a negative preference IIS is different from an interactive evolutionary art (evoart) system, in that difficult to define recombination operators that can produce poor quality hybrid (lethal) solutions are not required as they are in evoart.

A demonstration of the collaborative power of the conceptual IIS was demonstrated in an adaptive inter-office radio system by Chao, Balthrop, and Forrest "Adaptive Radio: Achieving Consensus Using Negative Preferences" technical report (2004), paper (2005). The software prototype was an MP3 broadcast system based on icecast, that required users to log in to have their negative music preferences take effect. User feedback (dislike of music) was provided track-wise (one song at a time), and the similarity function only considered album context. The problem of consensus for broadcast music is likened to deciding on where to go for lunch, or what movie to see with a group of friends. Unlike having to find an interaction of users positive preferences, some poorly described problems are easier to address through the union of user's negative preference sets - for some problems like the selection of office listening music it is easier to indicate dislike (negative preference) rather like (positive preference).

The observed results of the system indicated success, as more users logged into the system the available selection (non-rejection selection) narrowed. An observed problem was that the selection narrowed to the point where music was bland easy listening (elevator music). This was an interesting though understandable result; given music users (want to) listen to whist working is typically unobtrusive. The work indicated, further work needed to improve the similarity function for detectors, and perhaps partitioning music into streams with more refined scope (jazz, dance, country, etc.).

The idea of negative preferences is interesting, scalable and seems highly amenable to collaborative and interactive problem domains. It seems there is also plenty of scope for improvement, such as the use of aging detectors (dynamic or rolling over coverage), fuzzy or probabilistic detectors and refined domain-specific similarity functions and detector representations. I cannot help but relate these conceptualisation (IIS) with black lists and gray lists, and even with search stragies that use taboo lists (tabu search for example). It is clear that the broad ideas are not new. What is interesting, and exciting to explore are the applications of these ideas in larger scope problems (many thousands/millions of users on the internet), and on different types of problem domains. Clearly, the power of this technology (instance based negative preference) will not be complete realised until it is coupled with collaborative filtering, and positive preference systems.

Niching Particle Swarm Optimization

3rd September 2005

Particle Swarm Optimisation (PSO) is a search technique inspired by the group feeding and communication behaviour of schools of fish, flocks of birds, and plagues of insects (so called swarm intelligence). The approach typically models a problem using a number of particles and a multidimensional Euclidean space.

In nature, a population of organisms is not uniformly spread across a terrain, typically a populations is distributed across a wide spatial area and is divided into local or sub-groupings. Resources available to individuals across a geographical distribution can differ, and groupings of a species may specialise to exploit these differences. The effect of this species or population level natural selection is referred to as niching in the field of population ecology and population genetics. Niching permits a more effective use of allocated resources to a search algorithm on a single machine by implicitly and explicitly dividing and searching different areas of the space in parallel. The technique has proven useful when the complexity of the problem domain is scaled up to include multiple global and local deceptive optimal solutions - commonly referred to as multimodal problems.

I subscribe to the taxonomy proposed by Bäck, Fogel, Michalewicz "Evolutionary Computation 2 - Advanced Algorithms and Operations" (2000), that separates islands, niching and speciation by their biological inspiration. Islands are defined as multiple spatially distributed populations inspired by shifting balance theory and punctuated equilibrium, niching is inspired by the spatial distribution of a single species population (adaptive radiations), and speciation is inspired by divergence of population-sub groups (biological speciation), particularly in-group mating (selective breeding).

The standard form PSO algorithm can support some implicit niching by manipulating each particles neighbourhood size, where the larger population fractures into smaller groups that explore independently. As a niching approach, it is inefficient, as it relies upon serendipitous events during the running of the algorithm, a fact pointed out by Engelbrecht, Masiye and Pampara at this years IEEE swarm intelligence symposium in a paper titled "Niching ability of basic particle swarm optimization algorithms" (2005).

An objective function scaling technique called "*stretching*" was proposed by Parsopoulos, Plagianakos, Magoulas, and Vrahatis. An introduction and preliminary assessment of the technique was provided in a paper "Stretching technique for obtaining global minimizers through particle swarm optimization" (2001), another paper "Modification of the particle swarm optimizer for locating all the global minima" (2001), and a book chapter "Improving that particle swarm optimizer by function stretching" (2001). The intent of stretching is to manipulate the objective function such that the deceptive local optimal solutions are depressed or removed, leaving or perhaps revealing only the globally optimal solutions. This sounds like nothing more than function scaling or function squashing (ala sequential niching) which has been well studied in EC and in niching evolutionary algorithms. Either you need prior information about the modality and magnitude of the surface you are optimising, or you do a sensitivity analysis. (I could make a quip about niching in academia being a dangerous thing - but I won't.)

A technique called the *nBest PSO* to achieve a niching effect was proposed by Brits, Engelbrecht, and van den Bergh in a paper titled "Solving systems of unconstrained equations using particle swarm optimization" (2002). The approach broken the evaluation function into multiple constraints, and used an elitist

neighbourhood function. This work was extended by the same authors and an improved technique called *NichePSO* was proposed in "A niching particle swarm optimizer" (2002). The approach uses multiple sub-swarms, each particle having a radius that controls merging of sub-swarms when they intersect. This approach was investigated further in Bris' M.Sc thesis "Niching strategies for particle swarm optimization" (2002), it was further compared empirically and shown to outperformed two niching genetic algorithms - Beasley, Bull and Martin's sequential niching (1993) and Mahfoud's deterministic crowding (1995) - on some so called difficult function optimisation problems "Scalability of Niche PSO" (2003).

Finally, there are some additional niching PSO works of mention. Schoeman and Engelbrecht proposed a niching approach in a paper "Using vector operations to identify niches for particle swarm optimization" (2004), which was revisited and refined in "A parallel vector based particle swarm optimizer" (2005). The niching PSO used vector operations (dot products) to dynamically define the areas of the search space each sub-swarm of particles was permitted to search. A speciation version of PSO was proposed by Li "Adaptively Choosing Neighbourhood Bests using Species in a Particle Swarm Optimizer for Multimodal Function Optimization" (2004) called SPSO based on a species conserving technique for genetic algorithms, where the population is split based on solution similarity, and a species seed (cluster centre) is selected for each niche. The species approach SPSO was proposed to overcome limitations by Kennedy "Stereotyping: improving particle swarm performance with cluster analysis" (2000) that attempted to improve performance of the PSO algorithm in a similar manner, using a k-Means clustering algorithm. The SPSO niching approach was further used by Parrott and Li on dynamic function optimisation problems to track multiple optima "A particle swarm model for tracking multiple peaks in a dynamic environment using speciation" (2005).

Niching is a powerful and interesting behaviour in population-based search, and there are still very few works of niching applied to PSO search. I am not into niching PSO in my research, though off the cuff my intuition tells me I would approach the problem from a sharing (see fitness sharing genetic algorithms) perspective, where particle distribution is proportional to the expected payoff of a region in search space.

Immune Inspired Spatially Distributed Receptive Fields

6th September 2005

Scary title, simple concept - terminology can be a dangerous thing - though here I find it does aid in the conceptualisation of the proposed approach. I recently came across an interesting paper by Diao and Passino titled "Immunity-based hybrid learning methods for approximator structure and parameter adjustment" (2002). The crux of the paper is function approximation using a radial basis function networks that has been modified with growth and pruning approaches inspired by the acquired immune system. The approaches are called hybrid because of the use of structure modification approaches (immune inspired) as well as local-model refinement techniques (conventional least squares). Simple enough.

A radial basis function network (RBF or RBFN) belongs to the neural network computational intelligence genre and is primarily used for function approximation tasks, (classification and regression). The model (network) consists of a number of units (receptive units, detectors, "neurons"), each possessing a vector centroid in the input space and a kernel function (parametric, typically a Gaussian) that together define the membership of an input pattern to the unit. Each unit can have an associated nominal class (in the case of classification), or can use a constant weight vector to output a continuous value for the given input (regression). The technique is typically more flexible and less likely to converge to a local minima (prematurely arrive at a poor quality solution) than some other more common artificial neural network function approximations such as back-propagation. For a good jump-start on RBFN see "Introduction to radial basis function networks" (1996), by Orr.

Diao and Passino think about an RBF as a spatially localized model (input space). Each unit in the model is referred to as a receptive field as it is has a spatial region to which it is receptive to input patterns (produce output), which decreases monotonically from the receptors centroid to its defined boundary or width. Gaussian kernel functions are used with centroids and widths, as well as a linear input mapping in the form of constant weight coefficients on each attribute in the input pattern (trained using the least squares method).

The acquired immune system has a large number of detector (receptive units) cells or antibodies that continuously move throughout the host's circulatory system seeking potentially harmful antigens called pathogens. A theory proposed to describe the learning behaviour of a particular type of detector cell called a B-cell is the called the clonal selection theory, where upon detection of a pathogen a B-cell will produce many slightly-modified clones of itself in the attempt to improve affinity (matching) with the type of detected pathogen. A theory to describe the regulation of the systems detector cells is called the immune network model, which implies local communication and regulatory effects between detector cells. A feature of these theories that inspired Diao and Passino was the fact that the substrate of the acquired immune system is always changing. The individual cells of the system are in a constant state of flux being generated, aging, dying, and ultimately being replaced. Although the rate of change (learning) the system performs is on a lower time scale than the antigens the system is exposed to in this dynamic system, the system retains a memory of pathogenic exposures and the host stays alive.

These ideas were exploited by Diao and Passino who proposed two hybrid approaches for manipulating the centroids and widths of receptor units in a RBP network. The first approach called "*learning from clonal selection*" was a growth-based method for adapting the localised structure of the network. Starting with a very few receptor units, the system would use clonal selection-like proliferation of receptor units that

performed poorly, adding more units to areas that needed additional attention by the function approximator. This approach was preliminarily demonstrated successfully on a test function that contained both high and low frequency areas, where the technique added more receptor units to the busy (high-frequency) areas of the surface - as expected.

The second approach referred to as "*learning from internal affinity*" stated with an over abundance of receptor units, and pruned those units with low affinity (highest similarity to input patterns using Euclidean distance to the units centroid). This network pruning method did not perform as well on the same test function as the clonal selection growth method. The preliminary results indicated that perhaps applying the growth method first, followed by the pruning method may achieved improved results.

The techniques were applied to a dynamic case study jet engine model-development approximation problem. The structure adaptation techniques were compared to a grid based approach. Interestingly the growth-based method shown to be flexible enough to be applied at two levels of abstraction on the model, firstly at the receptor unit placement level in the inputs space, and secondly the approach was used to place entire "regional models" in the input space.

This preliminary work on structure modification techniques for RBF was based upon a previous report for an Intelligence fault tolerant engine control project for NASA, titled "Immunity-based hybrid learning methods for structure and parameter adjustment" (2000). Passino, is also the author of a book I have sitting on my desk titled "Biomimicry for optimization, control and automation" (2005). The takeaway point for me from this interesting paper, is the realisation of the relation between the RBF model and some of the coverage and exemplar based methods currently being preposed in artificial immune system literature. I had previously made the conceptual relation between exemplar-antibody models, nearest neighbour approaches, and vector quantisation approaches and now with RBF and similar network approaches.

I found the conceptualisation of network units as local receptor units and thinking of the RBF in terms of a localised spatially distributed model most thought provoking. Finally, it seemed that such a conceptualisation permitted the structure adaptation approaches used on the RBF to be raised a level in abstraction to be used to localise entire models. Perhaps this work could be further pursued, both in the placement of different types of localised models, and in the parallel refinement of model placement and unit placement during training.

Adaptive Radio and Product Propaganda

11th September 2005

I have just a quick note on the topic of adaptive radio. I discussed previously here the use of a negative preference system inspired by the immune system proposed by Forrest and her group at the University of New Mexico (UNM), specifically the use of negative preferences for adaptive radio.

About a week ago, whilst googe'ing on the topic, I came across a site called last.fm. I've been using the (**FREE!**) service for a week now and it matches my expectations of what adaptive radio should be, thus far. After signing up, I installed a winamp plug-in that sent all my listening behaviour to the site, building up a listening profile. This was nice - I was able to see reports of my listening behaviours, not something I'd thought about before in any detail. Finally, after building a large enough profile, the site calculated my "*user neighbours*" - users that have similar profiles as myself. This took a number of days to occur (about 400-500 tracks listened in my case).

After neighbours are calculated, the services provides a *neighbourhood radio* that plays music that you and your neighbours are expected to enjoy based on your profiles. The customised player for playing *neighbourhood radio* is very simplistic - though meets my needs just fine. There is an "**I love this track**" button (positive feedback), and a "**ban this track**" (negative feedback). There is also a skip track button.

I assume each user gets their own music stream, thus the skip track only effects each users listening experience. I also assume, that not pressing any buttons whilst listening (no feedback) is taken as indifference (will listen to again, but at a lower frequency than "*loved*" music). All tracks listened to over the neighbourhood radio feed are also added to the user profile – both broading the usres musical pallet and refineing their music profile at the same time. I have skipped very few tracks, and press the positive feedback button quite a number of times. I love this technology! The service providers valuable listening behaviour data to service operators, and the user get an very enjoyable and broadening musical experience. Did I mention that all the cool adaptive radio features I have described are free? Anyway, enough spam. Back to work.

Foundations, Conceptualisation, and Next Generation of Artificial Immune Systems

12th January 2006

I want to highlight (briefly review and discuss) three papers along the general theme of the abstract notions in the field of AIS, specifically a problem-oriented perspective for AIS, a conceptual framework for AIS and inspiration for next generation AIS based upon the proposed framework. All three papers have come out of Jon Timmis group (formally of Kent, and now at York), thus perhaps these papers that are spread over three years (‘03, ‘04, ‘05), are representative of his groups ponderings on theoretical formalisations and maturation of the field of artificial immune systems.

The first paper is titled "Revisiting the Foundations of Artificial Immune Systems: A Problem-oriented Perspective" 2003 by Freitas and Timmis. The paper focuses on the general negative selection algorithm for application to classification tasks. This algorithm involves the preparation of a pool of negative detectors - exemplars that do not match data of a selected task, inspired by the maturation of T-cells in the thymus. The paper has a machine learning perspective and raises the concern of representation and affinity measures (similarity measures), again highlighting the connection between negative selection-based techniques and lazy learning techniques (instance based learning). Further, the connection between representation, similarity measure, and inductive bias is highlighted.

The negative selection algorithm is a general idea/approach for binary and other classification tasks and in its general form, a number of problems in addition to those of representation and affinity measures are highlighted - some of which are mentioned to have been addressed in more specialised implementations. The core of the highlighted problems is in the context of the approaches inefficiencies. Specifically concerning the time required to prepare the exemplars related to the approaches undirected or random trial and error nature. This search process is mentioned to also not explicitly limit over-fitting of exemplars to the data or over-searching the search space for suitable solution components. The finally point attacks the very core of the approach - that of only maintaining negative exemplars, which perhaps is representative of not making full use of available problem-specific information.

The take-away message from the paper is an obvious one, that was/is perhaps overlooked by overzealous practitioners, and that is that the development of general algorithms is good, though a technique must be specialised to a problem to be useful or meaningful (thus the pushing of a problem-oriented perspective when revisiting the foundations of the field).

The second paper is titled "Towards a Conceptual Framework for Artificial Immune Systems" 2004 by Stepney, Smith, Timmis, and Tyrrell. The contention of the paper is that the field of AIS began with naïve models and abstractions of the immune system, and more recently has progressed to an engineering or problem focus. The authors suggest that for the field of AIS to mature and in an attempt to unify some of the varied forms of biological inspired computation, a general conceptual framework is required, that can be specialised for a given paradigm such as AIS. The authors encourage the development of improved general models which they claim does not conflict with the promotion of a problem-perspective for AIS in the previously discussed paper because the conceptual framework is intended to be specialised for a technique and it is presumed a problem.

A framework is suggested that includes a biological system, observations, abstractions and models, and finally the actual algorithms. The framework is two way permitting the analysis of existing algorithm, assisting in the development of new algorithms, and finally assisting in the development of models of biological systems. The framework is then discussed in a specialised form for AIS where population-based and network-based AIS algorithms are discussed.

It is suggested that such a conceptual framework would permit the field of AIS to mature through the development of abstractions and models (inspirations for new AIS algorithms) that pay more attention to the biological metaphor, though are not restricted to the metaphor. The development of these less-naïve algorithms is said to require interdisciplinary involvement from computer scientists, immunologists, and mathematicians. For me, these ideas are quite idealistic - the unification of the sub-fields biological inspired computation and the collegial interdisciplinary research with common goals, although interesting nonetheless.

The third and final paper is titled "Inspiration for the Next Generation of Artificial Immune Systems" 2005, by Andrews and Timmis. This paper provides a case study of the conceptual framework proposed in the previously discussed paper, and as such the case study provides an example for the development of a next-generation AIS. An alternative immunological theory referred to as Cohen's model is selected as inspiration over more conventional theories such as Burnet's clonal selection theory and Jerne's immune network theory.

It is this immunological theory that provides the interest in this paper. The model highlights high-level systemic properties such as maintenance, cooperation, emergent behaviours, and autoimmunity. Low-level processes highlighted include the use of multiple immune agents, signalling networks, feedback (positive and negative), degeneracy (generalisation), and pleiotropia and redundancy. An interesting point about a model inspired by this theory was raised by the authors which somewhat relates to my own work, as follows: "the notion the immune system as a concurrent and reactive maintenance system, lends itself well to application domains that operation in dynamic environments".

Although the work in the final paper is presented as a case study for the previously discussed conceptual framework, it is itself conceptual and abstract and as such gives the appearance of following any general common sense process for algorithm development (abstract models to algorithm to concrete implementation). In this regard the idea of going back to the foundations of the field and better-interpreting the biological inspiration is less than attractive for me. It seems this could be a similar trap as has been observed in the field of artificial neural networks where instead of innovating the approach, researches become pedantic with terminology and implementation. This is not what the reviewed conceptual framework proposed as was highlighted in the final paper through adopting an alternative immunological theory. If I were to extend (add my two cents) these thoughts of maturing the field, I would go as far as to say we need broader approaches/systems - that is the proposal of approaches that encompass more than a single specialised functionality of the immune system as described by a immunologists theory.

The Biological Immune System - Useful Resources

13th January 2006

I wanted to capture a few useful web resources for the biological immune system for those times when I have delusion of innovation and take it back to the theoretical immunological source. Come on, we all go there sometimes.

I want to start with some web pages. The Wikipedia immune system and immunology pages are a good first port of call for terminology and orientation, as well as interesting references such as the immunology wikibook. Another good introductory resource prepared by fellow AIS researcher Steven Hofmeyr is An Overview of the Immune System. The National Cancer Institute has a good page on the immune system, and the University of South Carolina school of medicine has a free online video lecture series on immunology which can be interesting to watch when in a procrastinating mood. There is also a short introduction to the immune system on the body website.

I get over introductory material fast and quickly move onto interesting and obscure facets that likely do not help with a broader understanding of the biological system, but are fun to get into nonetheless. There is an interesting article on technology review on using simulations to help understand the immune system. There is a fascinating article "Evolving Immunity" on talk design that argues the immune system can be evolved and does not have to be intelligently designed - it is interesting for its tone, detail and references.

Onto papers of interest. An old favourite is "Immunology for Physicists" (1997) by Perelson and Weisbuch, which although is a tome and quite dense in many places provides good discussion on many elements of the biological system with a analytical and critical view, as well as lots of excellent references. Perelson also provides "An Introduction of Computational and Theoretical Immunology" (2004) that is also worth a look. A classic early paper on using theoretical immunology to design a LCS like approach by Farmer, Packard, and Perelson is "The Immune System, Adaptation, and Machine Learning" (1986) on the learning, memory, and pattern recognition properties of the immune system.

There was a time when I was very interested in why evolution stuck with negative selection, so I read a lot about the evolution of the immune system. Some papers on this line of interest follow. "A general account of selection: Biology, immunology and behavior" (2001) by Hull, Langman and Glenn. "Actual Problems of Evolutionary Immunology" (2002) by Klimovich. "The descent of the antibody-based immune system by gradual evolution" (2005) by Klein and Nikolaidis. "Trade-offs in evolutionary immunology: just what is the cost of immunity" (2000) by Lochmiller and Deerenberg. There are a lot more papers on the topic, and likely a lot better papers, though these were the ones that I found and that peeked my interest. In the end, this line of investigation is out of scope for me.

Some final papers of interest are as follows. "The Acquired Immune System: A Vantage from Beneath" (2004) by Hedrick that again has strong evolutionary-immunology overtones. "The Danger Model: A Renewed Sense of Self" (2002) by Matzinger that provides a crash course on the Danger Model of immunology, and "Simulating the Immune System" (2000) by Kleinstein and Seiden that provies some interesting thoughts on computer simulations of immunological function.

This is a short list of some interesting resources on the biological immune system and is far from complete. I

would love to hear of any other interesting papers along the same lines - drop me an email or a comment.

The Clonal Selection Theory

16th January 2006

One of the main inspirations from the field of immunology for algorithms and approaches in the field of artificial immune systems (AIS) is the **clonal selection theory**, also called the **clonal expansion principle**. This post will provide a terse explanation of this principle and references to work in AIS that has exploited this principle. The intent is to highlight some of the language and phrases that - to me at least - hint at the potential of building systems inspired by this theory.

It is important to point out that the use of the clonal selection theory as an inspiration fin AIS can be equated to the use of Darwin's theory of natural selection in Evolutionary Computation (EC) or neuronal architecture in the human brain for Artificial Neural Networks (ANN). The connection I am trying to make here is that the inspiration is superficial and abstracted. At this point, we are only interested in general behaviours, and it is this statement that must be taken into consideration when immunologists and new researches begin to evaluate work in the field.

About a year ago I prepared a technical report "Clonal Selection Theory and CLONAG" (2005) on the theory and one algorithm inspired by the theory, I also prepared a software implementation of the approach for WEKA. Like Darwin's classical text "The Origin of Species by means of Natural Selection" (1859) being the classical theoretical reference for Evolutionary Computation, Burnet's text "The clonal selection theory of acquired immunity" (1959) is the classical reference for the clonal selection theory. Any good immunology textbook will provide a useful description of the theory. There is a detailed commentary of the history of the theory on nature - "The Clonal Selection Theory: what it really is and why modern challenges are misplaced" (2002) by Silverstein.

The crux of the theory is that through a process of *selection* the discrete cells of acquired immune system *adapt* to improve a defence to encountered antigen exhibiting properties of *learning* and *memory*. The process is triggered through a physical encounter between a antigen and the receptor cells on the surface of antibody. The antibody reacts by proliferating into a clone of cells, which differentiate - improving their affinity with the antigen and differentiate in structure producing more antibody cells and memory cells. This improvement of the affinity (matching between antibody and antigen) is referred to as affinity maturation (maturing of matching between surface properties of the antigen and the antibody cell receptors).

The theory was developed for B lymphocyte cells, although has been broadened for T lymphocyte cells, though given this heritage, inspired approaches in AIS are typically referred to as B-cell algorithms. Antigen molecules are foreign in that they are not native to the host organism, thus the selection and adaptation process is a refinement of the self-nonself discrimination process that the immune system is responsible for performing. The differentiation process used to improve the affinity of the antibody to antigen is referred to as somatic hypermutation - where the cells are varied in a natural selection-like mutation process.

The theory is said to be Darwinian in that a selection and differentiation process is applied to accumulate change (*learn*) over time. The term specificity is used to describe the ability of the system to specialise for a given antigen (a given molecular surface feature) and is measured in affinity (degree or quality of match). This matching process exhibits the ability to generalise, in that there can be a one to many relationship between what the antibody receptor will bind to and the types of antigens that exhibit the configured antigen

property.

Perhaps the more interesting of the work on AIS approaches inspired by the clonal selection principle is CLONALG by de Castro and Von Zuben - "The Clonal Selection Algorithm with Engineering Applications" (2000), "Learning and Optimization Using the Clonal Selection Principle" (2002). The Clonal Selection Algorithm or CLONALG was applied to three engineering applications - a TSP, multimodal function optimisation, and character recognition and its function was equated to evolution strategy (ES). de Castro provides an implementation of the approach for MatLab here, with documentation.

This approach was adjusted to exploit the inherent parallelism of the approach by Watkins et al. "Parallelizing an Immune-Inspired Algorithm for Efficient Pattern Recognition" (2003). The approach was made self-adaptive (parameter free) by Garrett in "Parameter-Free, Adaptive Clonal Selection". A variation of the approach called CLONCLAS is suggested by White and Garrett in "Improved Pattern Recognition with Artificial Clonal Selection?" (2003), and in "Dynamic Function Optimisation: Comparing the Performance of Clonal Selection and Evolutionary Strategies" (2003), Walker and Garrett apply a clonal selection algorithm to dynamic function optimisation and compare results to ES (the title suggests) showing the CS algorithm to outperform ES.

To summarise, clonal selection is all about a heterogeneous population of cells that are positively selected against for usefulness, where those cells that are most useful (highest affinity match to antigen) are proliferated and differentiated (hypermutated) in an attempt to improve response time and improve the affinity matching. The quintessential application of this abstraction of the clonal selection theory is the CLONALG algorithm that embodies the selection and mutation processes for engineering applications in a manner that is not too dissimilar to an evolutionary algorithm.

The Danger Model (the Danger Theory of Immunity)

16th January 2006

The **danger model** (also referred to as the **danger theory**) developed by Polly Matzinger in the early 1990's is a theory that attempts to address problems with the classical way of thinking about the immune system in terms of self-nonself discrimination. The theory is an improvement or extension over the classical self-nonself model for immunity, and proposes that that the immune system is more concerned with damage than with foreignness and is triggered by alarm signals rather than recognition.

This is an apparently subtle point related to the triggering mechanism for adaptation, although its ramifications imply that the foreignness of a pathogen is not the important feature in the model rather the damage the pathogen does to the self tissues and the alarm's raised as a result are what is important. The theory thus may also imply that the "*power*" of the immune system - its ability to adapt, may not be based in the cells of the innate or acquired immune system, but rather in the tissues tolerance and the conditions under which they raise alarm signals.

Some good references on Matzinger's danger model for the biological immune system follow - "An innate sense of danger" (1998), "The Danger Model: A Renewed Sense of Self" (2002), "The Danger Model in Its Historical Context" (2001), "Tolerance, Danger, and the Extended Family" (1994). There have between two main areas of research in the field of Artificial Immune Systems (AIS) in the development of approaches inspired by the danger model of immunity, they are in intrusion detection and in web mining (data mining on the web).

The first stake at indicating the potential usefulness of the danger model for the development of AIS was by Aickelin and Cayzer in "The Danger Theory and its Application to Artificial Immune Systems" (2002) which predominantly provided an useful introduction to the theory and outlined its potential use in anomaly detection using a more complicated triggering mechanism than in the conventional negative selection approaches. This work is extended by Aickelin et al in "Danger Theory: The Link between AIS and IDS?" (2003) and addressed in a poster by Greensmith et al "Detecting Danger: Applying a Novel Immunological Concept to Intrusion Detection Systems" (2004) and in a poster by Twycross in "Immune Systems, Danger Theory and Intrusion Detection" (2004).

The danger model is evaluated in applied by Secker, Freitas, and Timmis in a data mining domain, specifically in a dynamic email mailbox filter (classification) application "A Danger Theory Inspired Approach to Web Mining" (2003). This work is reiterated and extended in a book chapter by the same authors titled "Towards a Danger Theory Inspired Artificial Immune System for Web Mining" (2005).

Idiotypic Network Theory (the immune network model)

17th January 2006

The network model proposes that rather than the immune system being composed of a set of discrete clones that only respond when triggered by an antigen, that the immune system is a regulated network of molecules and cells that recognise each other in the absence of antigen. The theory suggests that antibody recognise antibody thus providing self-regulation of the immune response that could provide both inhibitory and excitatory maintenance effects.

The theory was initially proposed by Jerne in "Towards a network theory of the immune system" (1974) which is the classical reference for the idiotypic network theory. Some further useful references by Jerne on the model include "The Immune System" (1973), and "The immune system: A web of V-domains" (1976).

Farmer, Packard, and Perelson address a simulation of the network model for classification in "The immune system, adaptation, and machine learning" (1986) and explore the analogy to learning classifier systems (LCS). A model idiotypic network is discussed by Perelson in "Immune network theory" (1989). Relations to the connectionist ideas of parallel distributed processing (PDP) is discussed by Vertosick and Kelly in "Immune network theory: a role for parallel distributed processing" (1989).

There are been two primary areas of data mining research into AIS inspired by the immune network model, specifically into collaborative filtering (recommender systems) and self-organising clustering approaches.

Cayzer and Aickelin constructed a movie recommendation system inspired by the idotypic network model discussed in "On the Effects of Idiotypic Interactions for Recommendation Communities in Artificial Immune Systems" (2002) and in "A recommender system based on the immune network" (2002), and in a technical report "A recommender system based on idiotypic artificial immune networks" (2002). The simple AIS used antibody concentrations successfully in decision-making and regulation of overall population size.

A data clustering technique called aiNet is introduced by de Castro and Von Zuben in "An evolutionary immune network for data clustering" (2000) and in a book chapter "aiNet: An Artificial Immune Network for Data Analysis" (2001) that uses ideas from the idiotypic network theory and the clonal selection theory. A version of the aiNet algorithm is available for download here. The clustering algorithm's efficency was improved by de Castro and Timmis in "Hierarchy and Convergence of Immune Networks: Basic Ideas and Preliminary Results" (2002) where the approach was adjusted to construct a hierarchal network structure. The same authors adjusted the approach for application to multimodal function optimisation and renamed it to opt-aiNet in "An artificial immune network for multimodal function optimization" (2002). This function optimisation algorithm was further refined by Timmis and Edmonds in "A Comment on opt-aiNet: An Immune Network Algorithm for Optimisation" (2004).

The idiotypic network theory of immunity is predominantly theoretical with very few experimental immunologists working in the area. As such, the theory has somewhat fallen out of favour given the difficulty for further experimental work. From an AIS perspective, there may be strong relations between network based AIS and ANN's. Further, the regulatory (self-maintenance) behaviours of the model may be quite attractive for highly adaptive learning systems.

Lymphocyte Recirculation (Homing and Migration)

23rd January 2006

A feature of the biological immune system that attracted and inspired me early on in the development of my AIS was **lymphocyte recirculation**, also referred to as *lymphocyte migration* and *lymphocyte trafficking*. Superficially the topic refers to the mobility of lymphocyte cells and their movement through the vascular and lymphatic systems. This cell mobility facilitates two interesting migratory properties, specifically **homing** in which cells move from one point to another where they are needed in an immune response, and **recirculation** in which the cells move through various circulatory systems and tissues naively in search of being activated.

Lymphocyte migration (homing and recirculation) is taken as a canonical property of the immune system much like self-nonself discrimination and clonal selection. It efficient describes an important system property where the antigen repertoire is spatially distributed, rather than having a complete set of antigen at each lymphatic location - which would require an immune system an order of magnitude larger in terms of overall mass.

The mobile lymphocyte population in blood apparently accounts for approximately 1-2% of the lymphocyte population, and the mobile repertoire is turned over 10 to 48 times per day. The migration is blind as the discrete cells are naïve, although different cells have been shown to prefer specific recirculation routes through tissues and organs. Any good immunology text book will discuss lymphocyte migration.

The following provides some simple websites on the topic of lymphocyte migration (introductory). Lymphocyte Traffic and Homing are essential in in vivo immune responses. A brief discription of lymphocyte recirculation with a diagram. A definition of lymphocyte recirculation. A discussion of a research project into lymphocyte trafficing in the immune system. A researcher (Mentzer) of lymphocyte trafficing.

The following are some interesting research papers on the topic with useful references for further reading. Modelling of peripheral lymphocyte migration: System identification approach (2000), A model of lymphocyte recirculation (1997), Distribution Models of Recirculation Lymphocytes (1989), Lymphocyte migration in development and disease (1999), Lymphocyte trafficking and regional immunity (1999).

Problems in the field of Artificial Immune Systems

23rd January 2006

About a year ago I wrote an essay titled "On Biologically Inspired Computation", and in it I outlined what I thought were the big five contributions of the field, and the big five problems that need to be addressed. The problems were typical in that they referred to the lack of common nomenclature, lack of scientific rigor, the problems with representation, with suitability of application, and no free lunch. I was prompted today to think of the big problems in my field by a research colleague, and found myself scratching my head a bit.

From my understanding, the contribution of artificial immune systems (AIS) to the field of biologically inspired computation (BIC) is the computational approaches (lets call them algorithms) inspired by immunology (theoretical or otherwise). Specifically *clonal selection* algorithms, *negative selection* algorithms, *idotypic network model* algorithms and *danger theory* algorithms. Canonical application for these approaches are novelty detection/intrusion detection for negative selection, optimisation for clonal selection and danger theory and data mining for idotypic network model approaches.

The field of AIS is young - say ten years old, with the majority of the interesting work - publications by computer scientists being released in the last five years. The field is still in the exploration phase and thus the "*principles of the field*" (think step-wise construction for ACO or schemata for GA's) are still being established. This uncertainty is one of the selling points of the field that attracted me so - because of the alluring potential it offers.

With my previous big five BIC problems taken as a given, the five big problems in the field of AIS for me are as follows:

1. **Base models are too simplistic** - The models or abstractions taken a the inspiration for various AIS approaches are good for a first pass, though need to be refined for the field to mature. I am not necessarily taking about a unified AIS. (this is my selfish desire for more complex algorithms and larger scale AIS)
2. **Application domains are not fully realised** - AIS are learning systems, not limited to little prototype learning algorithms. These things can be used to solve some sickly large-scale, distributed problems not limited to canonical IDS and optimisation - we have not yet begun to realise the potential of these approaches.
3. **Lack of theoretical foundations** - Already outline by pillars in the field and mentioned in a previous post, this is obvious. For the field to mature, theory needs to catch-up to the prototyping and application of algorithms to try and explain how and why these abstractions work. I'm not sure when the right time for this will be - but defiantly after the field has settled down a bit (negative selection-based approaches may already be there).
4. **Related work infrequently leveraged** - EA's or even random search for clonal selection, SOM for idiotypic network approaches and LVQ and instance based learning for negative selection. Lots of lessons learned through many years of research in related fields that needs to be embraced, and leveraged to mature our field - let's not hide behind an obfuscated vocabulary.
5. **Poor understanding of the nature of the field** - AIS is combinatorial approaches for engineering application and all the related subfield that it entails. This is work completed by computer scientists

> (perhaps applied by engineers) that is inspired by work by immunologists, and is deciphered analytically by mathematicians. These boundaries can get fuzzy in literature, which is fine, we have to hit the field from as many angles as possible, although it is critical that the contribution a piece of work is having to the field is understood in an appropriate context. Theoretical immunology in AIS – good for an inspiration - but lets not get too far ahead of ourselves.

My big five have been given an emotive spin intentionally - I want to generate some discussion and provoke a reader response.

Introduction to Artificial Immune Systems

24th January 2006

This post is a letter to myself a year ago when I started in this area of research. It is designed to provide a useful batch of seminal introductory resources suitable to get started in the field of artificial immune systems.

Books are the best place to start and the best resource to use as an ongoing reference. There are four primary texts in the field as follows. Artificial Immune Systems: A New Computational Intelligence Approach by de Castro and Timmis (2002), Artificial Immune Systems and Their Applications edited by Dasgupta (1999), Immunocomputing: Principles and Applications by Tarakanov, Skormin, and Sokolova (2003) and Immunity-Based Systems by Ishida (2004).

The problem with books is the cost obviously and they take time to order and arrive - especially if someone else in your lab is in charge of your book-purchasing budget. Bring on the papers. Two seminal technical report references are provided by de Castro and Von Zuben. Artificial Immune Systems: Part I - Basic Theory and Applications (1999) and Artificial Immune Systems: Part II - A Survey of Applications (2000). An excellent book chapter available on the web by Timmis, Knight, de Castro and Hart is An Overview of Artificial Immune Systems (2004).

Some additional excellent starting point papers are as follows. Immunity-based Systems: A Survey by Dasgupta and Attoh-Okine (1997), Artificial Immune System (AIS) Research in the last five years by Dasgupta and Gonzalez (2003), and How do we evaluate Artificial Immune Systems by Garrett (2005).

Paper submitted on IIDLE

1st February 2006

I've finally got my act together and submitted a paper to the special session on Advances in Artificial Immune Systems at 2006 IEEE World Congress on Computational Intelligence, Congress on Evolutionary Computation (CEC2006). I'm excited about this special session because two of the players in the field are organising the session - Jon Timmis and Emma Heart.

The title of my paper is "**IIDLE: An Immunological Inspired Distributed Learning Environment for Multiple Objective and Hybrid Optimisation**". The following provides the abstract for my paper, which can be summarised as a discussion paper on my IIDLE framework.

Abstract
The acquired immune system is a robust and powerful information processing system that demonstrates features such as decentralised control, parallel processing, adaptation, and learning. The Immunological Inspired Distributed Learning Environment (IIDLE) is a clonal selection inspired Artificial Immune System (AIS) that exploits the inherent parallelism, decentralised control, spatially distributed nature, and learning behaviours of the immune system. The distributed architecture and modular process of the IIDLE framework are shown to be useful features on complex search and optimisation tasks in addition to facilitating some of the desired robustness of the inspiration.

Fingers crossed my paper gets accepted!

AIS Dissertation Bibliography

2nd February 2006

I have put together an Artificial Immune System (AIS) ***Ph.D. and Masters Dissertation Bibliography*** which is available here. The list includes a link to the thesis (if possible), date of publication, author with link to homepage (if possible), publishing university and complete abstract - very functional.

As far as I know it is complete as of the time of writing, including **15 Ph.D.** dissertations and **8 Masters** thesis. My intention is to keep the list updated throughout my Ph.D. program. The following provides a condensed list of each of the 23 AIS thesis titles and date of publication.

Ph.D. Dissertations

- A Study of Artificial Immune Systems Applied to Anomaly Detection (Gonzalez) (2003)
- An immunological model of distributed detection and its application to computer security (Hofmeyr) (1999)
- Antibody repertoires and pathogen recognition - the role of germline diversity and somatic hypermutation (Oprea) (1999)
- Artificial Immune Systems - A novel data analysis technique inspired by the immune network theory (Timmis) (2000)
- Biologically-inspired Autonomous Adaptability in Communication Endsystem - An Approach Using an Artificial Immune Network (Suzuki) (2001)
- Computational aspect of antibody gene families (Hightower) (1996)
- Exploiting Immunological Metaphors in the Development of Serial, Parallel, and Distributed Learning Algorithms (Watkins) (2005)
- Immune Engineering - Development of Computational Tools Inspired by the Artificial Immune Systems (de Castro) (2001)
- Immunology as a metaphor for computational information processing - fact or fiction (Hart) (2002)
- Integrating Artificial Immune Algorithms for Intrusion Detection (Kim) (2002)
- Modeling autonomous agents behavior using neuro-immune networks (Meshref) (2002)
- Negative representations of information (Esponda) (2005)
- Operating system stability and security through process homeostasis (Somayaji) (2002)
- The Cross-Reactive Immune Response - Analysis, Modeling, and Application to Vaccine Design (Smith) (1997)
- Towards a comprehensive view of the immune system (Carneiro) (1997)

Masters Thesis

- A spam detecting artificial immune system (Oda) (2004)
- AIRS - A Resource limited artificial immune classifier (Watkins) (2001)
- An Immune System Approach to Document Classification (Twycross) (2002)
- Anomaly Detection in Single and Multidimensional Datasets Using Artificial Immune Algorithms (Majumdar) (2002)
- Immunotronics - self-repairing finite state machines (Matthews) (2003)
- New Frontiers for an artificial immune system (Greensmith) (2003)

- Similarity Measure building for website recommendation within an artificial immune system (Morrison) (2003)
- Warthog - Towards a Computer Immune System for Detecting Low and Slow Information System Attacks (Williams) (2001)

Direct Search as a Local Hill Climber in Genetic Algorithms

27th February 2006

I have been thinking a lot about applying an effective local search (hill climbing) strategy to improve the results from a genetic algorithm - which is a global (course) search technique.

I started by looking for seminal works on GA Local search combinations. I came across "Optimizing Global-Local Search Hybrids" (2000), "When will a genetic algorithm outperform hill climbing" (1994), "When a genetic algorithm outperforms hill-climbing" (2004), and "Local Search and High Precision Gray Codes - Convergence Results and Neighborhoods" (2000). This search led onto many more case studies of GA's and hill climbers, as well as Lamarckian evolutionary algorithms, and Memetic algorithms.

What interested me specifically was the local-search strategy used in each case, I wanted some old-school papers on classical local search techniques - to ensure that when I slapped a strategy together I wasn't reinventing the wheel. I mean there can't be that many ways of doing a directed local search right? WRONG!

I fell straight into the field of **direct search** also referred to as **pattern search**. Pattern search refers to a class of (1960's & 70's) deterministic sampling techniques for function optimisation problems that do not require derivatives or partial derivatives of the objective function - sampling decisions are based solely on function value information (unlike techniques such as gradient descent). In this regard, the techniques are also referred to as zero-order methods. Moreoever, pattern search techniques also do not make a direct attempt to estimate the gradient to make a decision - thus they are very simple to implement and fast to execute. The algorithms belong to the nonlinear programming field of study, and there are many many of these things, many of which are variations on a the seminal techniques from the 60's. Some more popular techniques include the *Fibonacci Coordinate Search*, the *Hooke and Jeeves Pattern search* (direct search), the *generalised pattern search*, and the *Nelder-Mead method* (Wikipedia, Mathworld) (AKA the simplex method).

Some seminal and good introductory papers in the field of direct search include the following: "Why Pattern Search Works" (1998), "I know it when I see it: Toward a definition of direct search methods" (1997), "Direct search methods: then and now" (2000), "Direct Search - Solution of Numerical and Statistical Problems" (1960), "A Direct Search Algorithm for Optimization with Noisy Function Evaluations" (2001), "Direct Search Methods - Once Scorned, Now Respectable" (1996).

Armed with the knowledge that the field of pattern search exists - I researched the GA-pattern/direct search combination, and came up with a many papers. Some of the more interesting ones including the following: "Comparison of generalized pattern search and a genetic algorithm optimization method" (2003), "A comparison of a direct search method and a genetic algorithm for conformational searching" (1998), "A hybrid genetic algorithm with pattern search for finding heavy atoms in protein crystals" (2005), "Operational Optimization of Water Distribution Systems Using a Hybrid Genetic Algorithm" (2004), and "An improved algorithm for hydrologic optimization using the genetic search method" (1999). Also many works by William Hart, not limited to "Evolutionary Pattern Search Algorithms" (1995), and "Locally-adaptive and memetic evolutionary pattern search algorithms" (2003). I also came across an interesting combination of pattern search and PSO: "A particle swarm pattern search method for bound constrained nonlinear optimization" (2006).

The basic techniques have been around for 40 years, so there are many implementations around the internet, some examples include a Genetic Algorithm and Direct Search toolbox for Matlab including the *generalized pattern search (GPS)* algorithm and the *mesh adaptive search (MADS)* algorithm, and Mantissa an implementation of the *Nelder-Mead simplex method* and *Virginia Torczon's multi-directional method* in Java.

Extremal Optimization (EO)

1st March 2006

Extremal Optimization (EO) is a relatively new optimisation technique (developed in 1999, with 50 papers to date) inspired by a model of self-organized criticality from the field of statistical physics. A colleague of mine is working in this field of EO, so I thought I would read up on the technique.

Self-organized criticality (SOC) is a statistical physics model to describe a class of dynamical systems that have a critical point as an attractor. Specifically, these are non-equilibrium systems that consist of bursts of change and dissipations that reach up to the highest scales of the system. The model is said to govern the dynamics behind some natural systems that have this avalanche like phenomena including landscape formation, earthquakes, evolution via punctuated equilibrium (extinction events), and the granular dynamics of rice and sand piles. Some seminal references on this model include the following: "Self-organized criticality: An explanation of the 1/f noise" (1987), "Self-organized criticality" (1988), "Transport in Sand Piles, Interface Depinning, and Earthquake Models" (1996), "Ultrametricity and memory in a solvable model of self-organized criticality" (1996), "Aging Exponents in Self-Organized Criticality" (1997) and "Aging in a Model of Self-Organized Criticality" (1997).

Of special interest is the models ability to describe evolution via punctuated equilibrium - thus modelling evolution as a self-organised criticality. "Punctuated equilibrium and criticality in a simple model of evolution" (1993), "Evolution as a self organized critical phenomenon" (1995), "Avalanche dynamics in evolution, growth, and depinning models" (1996).

Another piece in the puzzle is work on computational complexity, specifically that critical points have been shown to exist in NP-Complete problems near optimal solutions, where near-optimum solutions are widely dispersed and separated by barriers in the search space causing local search algorithms to get stuck or thrash. "Where the Really Hard Problems Are" (1991), "Computational Complexity and Phase Transitions". It was the evolutionary self-organised criticality model by Bak and Sneppen and the observation of critical points in combinatorial optimisation problems that lead to the development of Extremal Optimization by Stefan Boettcher and Allon Percus.

EO was designed as an optimisation algorithm for combinatorial problem domains. Rather than working with a population of candidate solutions, the technique works with a single solution and makes local modifications to the worst components. This requires that a suitable representation be selected which permits individual solution components to be assigned a quality measure. This differs from holistic approaches such as ACO and GA that assign equal-fitness to all components of a solution based upon their collective evaluation against an objective function. The algorithm is initialised with an initial solution, which can be constructed randomly, or derived from another search process.

The technique is a fine-grained search, and superficially resembles a hill climbing (local search) technique. A more detailed examination reveals some interesting principles, which may have applicability and even some similarity to broader population-based approaches (EC and AIS). The governing principle behind this algorithm is that of improvement through selectively removing low-quality components and replacing them with a randomly decided component. This is obviously at ends with the quintessential evolutionary computation algorithm that selects good solutions in an attempt to make better solutions. The resulting

dynamics of this simple principle is firstly a robust hill climbing search behaviour, and secondly a diversity mechanism that resembles that of multiple-restart search. Graphing holistic solution quality over time (algorithm iterations) shows periods of improvement followed by quality crashes (avalanche) very much in the manner as described by punctuated equilibrium. It is these crashes or dramatic jumps in the search space that permit the algorithm to escape local optima and differentiate the approach from local search procedures. Although such punctuated-equilibrium behaviour can be "designed" or "hard-coded", I will stress the point that this is an emergent effect of the negative-component-selection principle fundamental to the algorithm. (Reminds me somewhat of the negative selection algorithm in the field of AIS)

EO has primarily been applied to combinatorial problems such as graph partitioning and TSP, as well as problems from statistical physics such as spin glasses. Seminal works on EO and tau-EO (the canonical EO) include the following: "Extremal Optimization - Methods derived from Co-Evolution" (1999) , "Extremal Optimization of Graph Partitioning at the Percolation Threshold" (1999), "Optimizing partitions of percolating graphs" (1999), "Combining local search with co-evolution in a remarkably simple way" (2000), "Nature's Way of Optimizing" (2000), "Extremal Optimization - Heuristics via Co-Evolutionary Avalanches" (2000), "Optimization with Extremal Dynamics" (2001), "Extremal optimization for graph partitioning" (2001).

Other general references include the following: "Jamming Model for the Extremal Optimization Heuristic" (2002), "A Bose-Einstein Extremal Optimization Method for Solving Real-World Instances of Maximum Satisfiablility" (2003), "Efficient Initial Solution to Extremal Optimization Algorithm for Weighted MAXSAT Problem" (2003), "Extremal optimization - an evolutionary local-search algorithm" (2003), "Improved extremal optimization for the Ising spin glass" (2004), "Large-Scale Applications and Theory of Extremal Optimization" (2004), "Comparing extremal and thermal Explorations of Energy Landscapes" (2005), "Extremal Optimization - New Optimization Algorithms in Physics" (2005), "Extremal Optimization at the Phase Transition of the 3-Coloring Problem" (2005), "Extremal Optimization for Sherrington-Kirkpatrick Spin Glasses" (2005), "Optimizing at the Ergodic Edge" (2005)

Generalised Extremal Optimisation (GEO) was developed to operate on bitstrings where component quality is determined by the absolute rate of change of the bit, or the bits contribution to holistic solution quality. This work includes application to standard function optimisation problems as well as engineering problem domains: "Function Optimization Using Extremal Dynamics" (2002), "New stochastic algorithm for design optimization" (2003), "Generalized Extremal Optimization for Solving Complex Optimal Design Problems" (2003), "Generalized Extremal Optimization - A New Meta-heuristic inspired by a model of natural evolution" (2004), "Generalized Extremal Optimization - An application in Heat Pipe Design" (2004), "Generalized Extremal Optimization - An Overview of a New Evolutionary Optimum Design Tool" (2004), "Heat Pipe Design Through Generalized Extremal Optimization" (2004), "Spacecraft thermal design with the generalised extremal optimization algorithm" (2004), "Structural Optimization With the Generalized Extremal Optimization" (2005).

Another extension is Continuous Extremal Optimization (CEO) "Continuous extremal optimization for Lennard-Jones clusters" (2004). EO has been applied to image rasterization as well as used as a local search after using ACO "Ant Colony System with Extremal Dynamics for Point Matching and Pose Estimation" (2002), "Combining extremal optimization with singular value decomposition for effective point matching" (2003). EO has been used to identify structures in complex networks "Community detection in complex networks using Extremal Optimization" (2005). EO has been used on a multiple target tracking problem "Extremal optimization for sensor report pre-processing" (2004). Finally, some work has been done on investigating the probability distribution used control selection "Fitness threshold accepting over extremal

optimization ranks" (2004), "Best possible probability distribution over extremal optimization ranks" (2004).

Differential Evolution (DE)

6th March 2006

Differential Evolution (DE) is a evolutionary algorithm (EA) that operates upon real-valued vectors - taking weighted differences between two population members and adding them to a third population member. This fast and simple algorithm is quite similar to real-valued genetic algorithms (GA) and evolution strategies (ES), and has been demonstrated as being an effective search technique in real-world problem domains. I have recently implemented a few variations of the technique, and my initial empirical evidence (on test and competition datasets) shows DE to be a competitive search technique.

The technique was developed and refined by Rainer Storn and Ken Price. There is a Mathworld article on DE here, and a similar Wikipedia article here. By far the best reference I've read on the algorithm is "An introduction to differential evolution" in the book "New ideas in optimization" - simply because pseudo-code examples.

Some seminal publications on the technique include the following:

- Differential evolution - a fast and simple numerical optimizer (1996)
- Minimizing the real functions of the ICEC'96 contest by Differential Evolution (1996)
- Differential evolution design of an IIR-filter (1996)
- On the Usage of Differential Evolution for Function Optimization (1996)
- Differential Evolution - A Simple and Efficient Heuristic for global Optimization over Continuous Spaces (1997)

Storn has an excellent introductory page here, which includes references, books and software. A DE bibliography is available online on Jouni Lampinen's website here.

Particle Swarm Optimization (PSO)

8th March 2006

I am still working away on the CEC2006 function optimization competition. I thought I would try **Particle Swarm Optimization** (PSO), and benchmark it against some of the other techniques I've been trying (GA, Real-Value GA, Differential Evolution, etc...). I did some reading and tried some rules of thumb for applying the technique that apply to the surfaces in this competition. Although I have posed on niching particle swarm optimization before, I thought I would capture here the seminal papers for the inception of the technique, as well as the seminal works that introduce the field of study.

The optimization technique is inspired by the behavioural dynamics of flocks of birds (and other swarm intelligences), most notably demonstrated by Craig Reynolds with Boids.

Inspirational Papers
- Flocks, herds and schools - a distributed behavioral model (1987)
- A stochastic nonlinear model for coordinated bird flocks (1990)
- Particle systems - a technique for modeling a class of fuzzy objects (1983)
- Swarms, Phase Transitions, and Collective Intelligence (1993)

The PSO technique was invented by James Kennedy and Russell Eberhart in 1995. The technique has been empirically shown to be more effective on higher-dimensionality problems, meaning it may not be a good choice for the competition (my current experimental results further support this guideline).

Seminal papers
- Particle swarm optimization (1995)
- A New optimizer using particle swarm theory (1996)
- The Particle Swarm - Social Adaptation of Knowledge (1997)
- Evolutionary optimization versus particle swarm optimization - Philosophy and performance differences (1998)
- A modified particle swarm optimizer (1998)
- Small worlds and mega-minds - Effects of neighborhood topology on particle swarm performance (1999)

There is a Wikipedia article on PSO here, and on Swarm Intelligence here. There is a good website on PSO here, with a useful introductory tutorial and PSO paper bibliography (as of 2004). There is a PSO toolbox for Matlab here, and a swarm intelligence Wiki here. Finally, there is another good introductory article here. I highly recommend the books "Swarm Intelligence" (2001) by Kennedy and Eberhart, and the chapter 25 "The Particle Swarm: Social Adaptation in Information-Processing Systems" by the same authors in "New Ideas in Optimization".

Continuous Function Optimization (Software)

13th March 2006

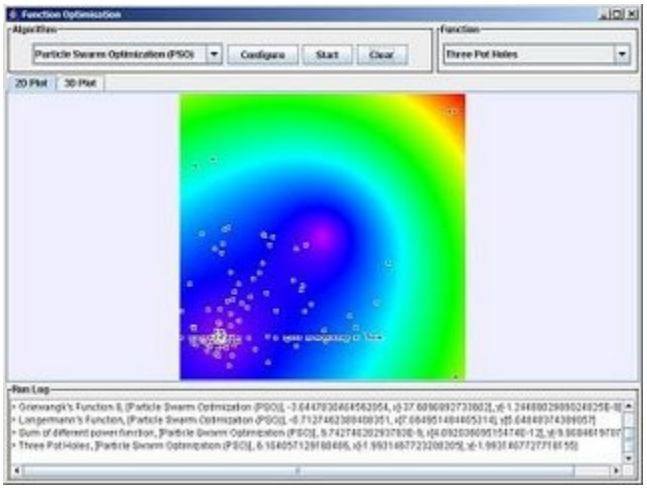
With all my recent research activity focused on function optimization for the CEC2006 competition, I have implemented and been evaluating the sampling behaviour of many standard function optimization techniques. As an outcome from all this hard work I have bundled all the algorithms and test problems I've been using together and provided them as a piece of educational software (with source code).

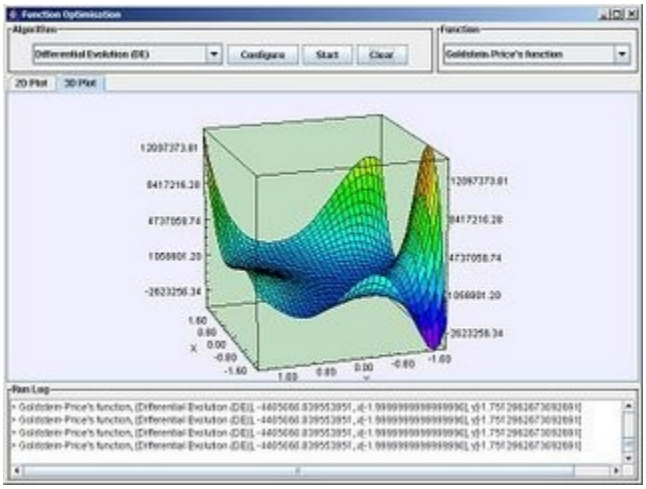
The software provides 2D and 3D visualisations of test problems, provides algorithm configurations, and limits function evaluations to 10,000 per run. It is designed not to "race" algorithms, but rather to play-with them to gain insight into their sampling behaviour.

The following list algorithms are provided, although I have designed the software such that it is very easy to add further techniques and problems, so I plan on adding many more over the coming months.

- Simple Genetic Algorithm (GA)
- Real-Valued Genetic Algorithm (RVGA)
- Evolution Strategies (ES) (mu-lambda)
- Differential Evolution (DE)
- Particle Swarm Optimization (PSO) (g-best)
- Random Search
- Uniform Search (grid)

The following are screenshots of the software:





The program can be run in the browser as an applet or can be downloaded and run as an offline application. Source code is provided. There is a page setup for the software here. Enjoy.

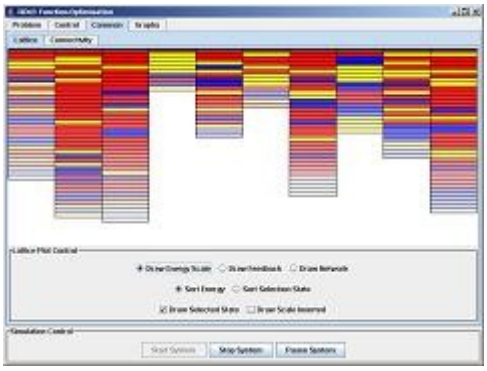
Suggest any features or algorithms for me to implement???

IIDLE Software Online!

22nd March 2006

Well my paper to CEC'06 on IIDLE was accepted - YAY!

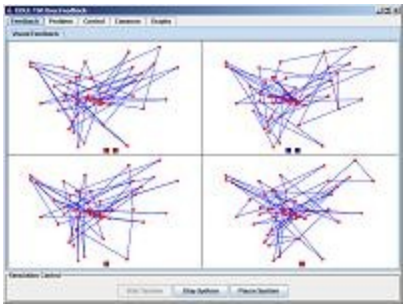
To celebrate I have put up a web site on IIDLE (Immunological Inspired Distributed Learning Environment) that provides an overview of the platform, the conceptual model, the vision for the platform and heaps of example scenarios for using it with offline and online software. That's right, **you can play with IIDLE from within your web browser** (java applets)!



The scenarios include the following:

- **Basic Optimisation**
  - **TSP example**
  - **Function Optimisation Example**
  - **Protein Folding Example**
- **Multiple-Objective Optimisation**
  - **TSP example**
  - **Function Optimisation Example**
- **Hybrid Technique Optimisation**
  - **TSP example**
  - **Function Optimisation Example**
- **Human-Feedback Objective Function**
  - **TSP Example**
- **Networked (P2P) Collaborative Optimisation**
  - **TSP Example**
  - **Protein Folding Example**

I'm excited about this and would *LOVE* to hear any comment or criticism of the platform and or the software implementation.



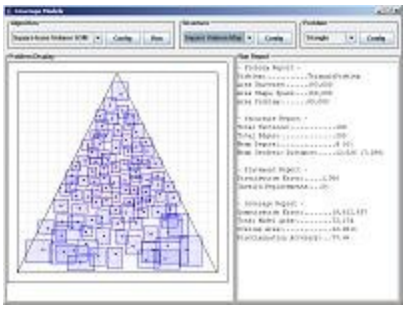
Enjoy!

Coverage Models in 2D

23rd March 2006

About a year ago I spent a few weeks building and testing SOM and LVQ inspired coverage models for simple 2D problem domains (collections of polygons) . The work was inspired by some research I was reading about regarding immunological-inspired coverage models being used for novelty detection and anomaly detection using the negative selection algorithm.

Anyway, I was thinking about that work recently and decided to dig it out. The software made some pretty pictures and such so I've made a simple website for it, and put the software in an applet so it can be played around with online.



Enjoy!

Combinatorial Optimization (Software)

30th March 2006

A few weeks ago I released some function optimisation software with a stack of test problems and algorithms. In the same manner, I have built and released similar software for combinatorial optimisation - specifically TSP. The algorithms implemented thus far are mostly ACO based, although the framework is suitably modular and extensible like the func opt software. Check out the page for the software as well as the applet.

The following is a list of available algorithms:

- **Simple Genetic Algorithm (GA)**
- **Greedy Search**
- **Ant System (AS)**
- **Rank-Based Ant System (RBAS)**
- **Max-Min Ant System (MMAS)**
- **Ant Colony System (ACS)**
- **Random Search**

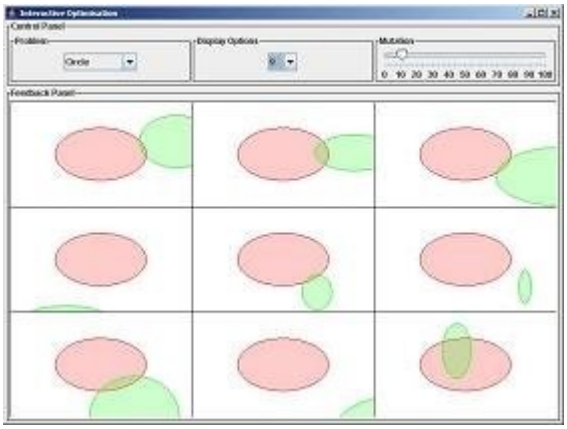
Enjoy.

Human Interactive Optimization

6th April 2006

While resurrecting and revamping my old SOM-based coverage experiments I had a few ideas about human-based objective functions for simple coverage problems. The result is a new piece of software I wrote yesterday afternoon on a whim. It's a basic blind watchmaker based interface that provides a simple random search algorithm and a few simple polygon based coverage problems.

The human as the pattern-matching objective function sort of works in this example, although it is less than efficient and a little boring. I still really like the idea and I expect I'll keep noodling around with it until I hit the right application / representation / approach.



I'd love to find a way of hooking these ideas in with my research on artificial immune systems (IIDLE), not too unlike the paper "Generating Biomorphs with an aesthetic immune system" (2002) by Chao and Forrest.

Check out the web page for the software and the online applet.

Evolution is cleverer than you are

20th April 2006

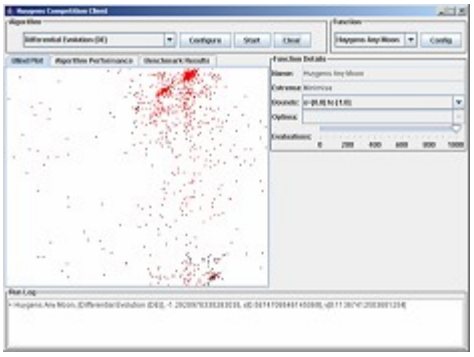
Just a quick one. I finally found some time to listen to the audio recording of the public lecture - The Selfish Gene: thirty years on, and I must say that I really enjoyed it. Check out the transcript, and the mp3 of the recording, the page for the lecture on Edge and the post on Boing Boing last month.

One little throw away quote by Daniel Dennett's part of the lecture which I thought was kind of cute was "*Evolution is cleverer than you are*". This is actually referred to as Orgel's Second Rule, more information can be found on the Wikipedia article. Cute as I said, and what it was intended to refer to was the fact that some aspect of nature may appear pointless or not make much sense, and later on it is discovered that it plays a part in some ingenious design.

Huygens Probe Competition (CEC'06)

20th March 2006

I have released some software for the Huygens Probe Competition which is apart of CEC'06. The software supports a GUI with lots of pretty graphs and such, as well as 14 standard computational intelligence algorithms and various benchmark modes. A dedicated site has being created for this software, so anyone interested in getting involved in the comp who is not interested in programming, check it out.



Enjoy!

Nerd theology

1st May 2006

I recently read Nerd theology by Kevin Kelly. Short, and intersting, and although the premise is elementary to any serious programmer or student of AI I enjoyed it. Here are some fun take away quotes:

Indeed the mussion of AI is not to make a human mind but to explore the "space" of possible intelligences.
The great shiver that computer chips and glass fibers are sending through our consciousness... is due to this technology's remarkable aptitude for regenesis.
...the creator created humans in his image, and so we too are creators... we are becoming derivative gods ourselves.
The ongoing scientific process of moving our lives away from the rule of matter and toward abstractions and intangibles can only prepare us for a better understanding of the ultimate abstraction.

Toward to CEC'06

5th July 2006

Well, I'm off to the 2006 IEEE World Congress on Computational Intelligence (departure is on Tuesday 11th of July) . I have a five day stop over in San Francisco first where I'm meeting with my supervisor and Irene (another colleague from CISCP). Then, its off to Vancouver for the conference.

I'm presenting my work on the first day (Monday 17th July) in the Special Session on Advances in Artificial Immune Systems. I have my slides and such ready, but I'm still scared as hell presenting my paper infront of the peers in my field (Timmis, Hart, and others).

My intention is to blog my experiences and thoughts while my over there. I'm booked into tutorial sessions on the Sunday, and my intention is to go to a lot of sessions out side my normal areas of interest - try and get some exposure to some new ideas.

CEC'06, Day 2, Morning

18th July 2006

Well it's day two of CEC'06, and I have my talk this afternoon in the finroom (AIS special session). Yesterday was cool, although long. It was a day of registration and tutorials, and we (Tim, Irene and myself) attended three.

First up was De Jong on evolutionary computation (EC). He was a great speaker, and although the material was basic (known to me), it was still an entertaining talk. Specifically his attempts at unification and abstraction of the field of EC. It struck a cord with my desires for a general method of application, which he sort of had - a trial and error, problem-based approach. See below for a shot of De Jong.

The second talk I attended was Evolutionary Robotics by Floreano. Not a field I know that much about, although it was very interesting nontheless. Lots of discussion of evolving different types of neural networks as robot controllers, and lots of videos of real-robots testing out controllers.

The final tutorial for the day was by Dev on multiple objective optimisation. Deb was fantastic althought I was stuffed (no sleep), so the good technical details went over my head. Dan would have loved it, so I took a video just for him :) See below for a photo of Deb.

The reception drinks was cool - free drinks are always cool. I meet a stack of names I was familar with, shook the hands of Deb and Dasgupta. See below for a shot of Irene and tim enjoying some (Australian!!!) wine. Having a ball, wish me luck for my talk!

CEC'06, Day 2, Morning

19th July 2006

Well it's day three of the conference in the morning, and yesterday was a big and a long day. I was pretty stressed about giving my talk, so I didn't really concentrate on any of the talks I saw during the morning. The highlight was a lunchtime meeting with the AIS (Artificial Immune System) community to discuss the future of the field.

It was great to be in the same room as many of the researches that created and shaped my field of research (de Castro, Hart, Lamont, Dasgupta, Stibor, etc... I can't remember all the names). Some of the take away points for me from the meeting were:

- The need to work closer with immunologists to assist them in developing new and or better abstractions to understand the biological system, and new computational models
- Perhaps the field is stuck, there has been few innovations in the field in the last five years, although perhaps this focusing on existing models is a part of the maturation of the field
- The need to perhaps take a systemic or holistic view in developing new AIS, rather than developing smaller algorithms that are inspired by a single aspect of the system
- The concern that there is no killer application for AIS, that the approaches are OK at a lot of things, but not state of the art at anything
- The need to make software and source code available online
- Finally, Lamont made an excellent comment related to my work, that the immune system does not converge, that this idea of convergence is an idea from optimisation, for me this was related to the idea of "always-on", that the system is suited to monitoring like problems rather than optimisation domains that have an end-point

The AIS special session was great, although sadly Jon Timmis couldn't make it, so Emma Hart chaired the session. My talk was 3rd (in the middle of the session), and it went OK, no major screw-ups. Although, I believe I had too many concepts in there. Also, it was a shame that the audience as filled up as it could have been. Stibor's talk was very good, if not a bit dense for me in presentation format, also the talk on fault detection in power distribution systems was interesting only because I'm quite familar with Watkin's AIRS approach.

Below is a photo of me during the start of my presentation (cheers Irene).

After my session we (Irene, Tim and myself) went off to a plenary session on IPD, specfically reputation in the iterated prisoners dilemma by Xin Yao. He's a really nice guy, and a good speaker, although I found his talk a little boring - not really my interests. See below for a photo of Yao.

After the talk we hooked up with the RMIT boys (Stefan and Xiaodong) and went out for Mexican food. Today should be interesting, a whole lot of swarm intelligence sessions for me. This is because Stefan, Tim, and Irene all have their talks today. Also, I missed a talk by David Fogel this morning, damn conflicts. I guess that's the cost of having like 12 parallel streams.

Computational Intelligence in Games

19th July 2006

We attended a plenary talk this morning after the first session titled "Computational Intelligence in Games" presented by Risto Miikkulainen. It was an inspiring talk which covered GOFAI in borad games (briefly), and more interestingly focused on AI in video games (FPS and RTS).

Some research on using evolutionary neural nets in unreal tournament was presented, work which I had seen before. More interestingly to me, he presented work on a project called NERO (Neuro Evolving Robotic Operatives). Basicall this is a game platform for training groups of agents with neuro-evolutionary techniques, and I look foward to having a play (likely on the plane ride home). See below for a screenshot of the software taken from the NERO website.

CEC'06, Day 3, Afternoon

20th July 2006

Well, we have now all done our presentations. Both Tim and Irene went well in the PSO sessions, both of which were chaired by our friend at RMIT; Xiaodong. We hit the town last night and got into some Canadian beer. Tim also won the award for best paper in his session. See below for shots during their presentations.

We had a great plenary session last night by Marco Dorigo on Swarm-bots (known as s-bots). i had read about this research again, but it was great to hear it from the mouth of the project leader. He had lots of great videos demonstrating collective and group behaviours, very cool stuff. The one take-away point for me was his mention of a a new project called Swarmanoid. Basically the project involves different robot types (eye-bots, hand-bots, and foot-bots), and ways for these different (heterogeneous) bots to communicate and work together. See below for a photo of Dorigo during the presentation.

This morning we attended a very interesting plenary talk by Sebastian Thrun on the DARPA Grand Challenge. Specifically on the work he and his Stanford group did to win the challenge with their system called Stanley. He also mentioned that it may be worth checking out the Nova doco titled "The great robot race" which is available free online. A quite inspiring talk, I must say.

Not much else interesting to note. Irene said there was an interesting paper or breaking down PSO in the first session this morning by Kennedy, but I slept through it. We have the conference dinner tonight, and before then I believe there is an interesting plenary talk on coevolution and at the same time something on neural nets by Widrow.

Final Day, Afternoon

22nd July 2006

Well, I am currently sitting in the final plenary talk (on the history of EMOO by Carlos A. Coello Coello) on the final day of CEC2006. I blew off yesterday, and most of today to explore Vancouver, and I had a ball.

The last event I can remember was Wednesday night when we had the conference dinner. Dinner was good, although long. We had a salad, salmon for the main (of course), and some desert which was quite sweet. The wine was local, and was OK, although not nearly enough.

I sat with Tim, Irene, a stack of randoms, and Andries Engelbrecht (one of the guys who invented PSO, among many other research highlights). He's a cool guy, and as a group we had fun. We bailed during the award presentations, too boring. It was a good night all in all.

Collaborative Drawing

2nd August 2006

Something that I have been intrigued about for a while is this so-called real-time collaborative art. What I am referring to is a number of sites I have seen pop up recently on reddit or digg that permit open-ended real-time collaboration on a drawing canvas.

I thought I'd search for and collect a few of these sites and disseminate some general principles with perhaps the future intent of testing out some of my own ideas of incorporating some sort of underlying evolutionary process. Anyway, below I have presented a brief summary of few sites I came across in an hour or so of google'ing. Please post if you are aware of more or similar sites.

- **The Broth Global Mosaic** - A very cool idea of giving the users 1000 coloured tiles to play with and construct some kind of mosaic. It provides additional features such as private rooms, chat, user moderation (user karma system), and tutorials on how to implement some of the ajax features seen on the site. It seems to have been built by Markus Weichselbaum (in 2006?) as a folio piece for his company. See the main public mosaic, the gallery, their blog, and the history of the site.

- **Beauty and chaos in time and space** - A multi-user drawing piece created by Eric Deis in 2001, that sends information to a gallery from which a projected image and sound effects are derived. The collaborative canvas allows the user to draw lines which age (decay) with time to reduce the messiness of the image.

- **Drawball** - An enormous circular canvas that is first presented at the macro level, and which permits the user to zoom into an area of the image to begin their contribution. The higher level reveals a lot of graffiti in the form of images and characters of all types, whereas the lowest level reveals words and in some cases seemingly random subcomponents of the larger graffiti. The site has a gallery and is also mentioned on Wikipedia.

- **Mosaic Paradise** - A less pretty, although just as effective site. Mosaic Paradise allows the user to place and manipulate pre-fabricated objects such as bricks and letters onto a specialised canvas. Rather than art, the site describes the project as a collaborative game. There is a small gallery of works. Unfortunately, the sites does not work in my firefox.

- **Community Pixel Art** - This appears to be a collaborative art experiment by Steven Buss (2006) where users turn pixels on or off (black and white image). The site also provides a suggested image for the users to recreate. Very simple, although still interesting, and the author provides the source code for the project.

- **Shared Canvas and Chat** - As its name suggests, this is a shared drawing canvas that also permits text messages to be posted. It is provded as a sample application for the JavaScript O Lait (jsolait) project. Again, another very simple example.

General Principles

I have provided three very good examples and three more rudimentary examples of the type of collaborative drawing systems that I have been thinking about of late. Specifically, the first and third systems match my vision for such a system. Rather than collaborative art, the open-ended systems are like mutable public drawing space or online graffiti walls where on occasion a group of like-minded users are capable of creating a mural of sorts.

I think for these systems to be effective, the user must be made aware of the collaboration in real-time. The lines or blocks (or whatever) should and are shown to appear or be drawn asynchronously by invisible hands, and it is this (seemingly) instantaneous visualisation of other users contribution that makes these systems work or be fun. Also, showing the number of concurrent users doesn't hurt.

The addition of a gallery of produced images, whether time-lapsed or stills is also an excellent way of making the users feel like they are apart of something larger. Kind of like walking past a graffiti wall every day (in the real world) and observing the transient additions and augmentations over time. That being said, the systems require some mode of decay, whether it be a peridotic canvas clear, aging of brush strokes or whatever. Not all systems need such a feature explicitly, user's can provide the decay either through rearrangement or through painting over the top.

These systems do appeal to me, if only for their aesthetics, their emergent properties and, the technical thoughts that they provoke in my head if I were to build such a system. Now I have to try to crack the nut of getting some kind of evolutionary process mixed in there - it just feels like such a good fit.

AIS and CIS

7th August 2006

I came across an useful list of all the Artificial Immune System (AIS) papers and posters at CEC2006 (WCCI2006) on Paul Andrews webpage at the University of York.

Also, my research group has been renamed to a lab and is now called "Complex Intelligent Systems". Anyway, we have started a group blog. I'm posting mainly links to interesting research on that blog, and save my rants and reviews for this blog.

Online Interactive Evolutionary Processes

10th August 2006

I have been searching for and collecting links of online interactive evolutionary processes for about a week with little luck. They appear to be quite difficult (for me to locate). My criterion for such a system is that it must permit user interaction via a real-time user-based cost function or manipulation of the evolutionary process in some way and it must be online (typically implemented as an applet, flash, AJAX, etc.). Also cheers to Jer Thorp why put up a call for links on his blog.

These systems can be called many things it seems; interactive evolutionary computation, human based genetic algorithm, interactive genetic algorithm, evolutionary art, collaborative evolution, generative evolution, etc. A good survey on the technique is provided by Hideyuki Takagi: "Interactive evolutionary computation: fusion of the capabilities of EC optimization and human evaluation", 2001. Also, evoweb have a page on evolutionary art, and Matthew Lewis has a site dedicated to collecting links on the topic.

A classical example of the type of systems I've been searching for are the generative L-system blind watchmaker applets, of which there are zillions (1, 2, 3, 4, 5, 6, 7, 8). Boring, these ideas and technology are capable of so much more.

- I made a (pretty crap) human interactive optimisation applet earlier this year for matching shapes onto templates.
- Simon Levy has created something interesting called Blind Watchmaker IFS Applet for evolving a set of pixels into an image, perhaps backed by a neural controller.
- Josh Lee created a simple pair-wise voting system for GP-based evolutionary images called Evolve.
- Henry Rowley has an applet for evolving pretty images of fractals with source code.
- The most recent incarnation of geneticArt (geneticArt IV) by John Mount (and others) is online as an applet and permits the evolution of images based on formulae.
- Michael "Flux" Chang has an interesting project called Morphology which involves the evolution of multi-cellular creates with springs, muscles, sensors and neural controllers for swimming and light following (details, project). The project does provide limited human interaction with the evolutionary process.
- Finally, there is a very sexy applet called Disney meets Darwin that allows human interaction with and evolutionary process for getting stick figures to walk.

I know there are heaps more examples out there, I remember playing with a few myself, I just cannot find the links - so comment or email me if you know of some more examples!

It strikes me that the concept of an online (internet as a platform) for interactive evolutionary processes is far from being exploited effectively. The dominant implementations are Java applet-based is aesthetics applications with basic l-system and GP-tree representations (with a few exceptions and assuming the links I've collected are a fair sample).

What I would like to see is firstly AJAX as the implementation technology specifically for its fast-to-load, slick interface and real-time collaboration visualisation capabilities. I also strongly believe that more interesting/exciting aesthetic applications are possible (get on generative artists), but more than that I believe

some seriously interesting search and optimisation problems can be addressed in this way.