Individuality, Control Systems and Computer Networks

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Outline

The problem in commercial computing terms
The biological metaphor.
The Insufficiency of protein coding to account for speciation and individuality.
Non-coding RNAs
Signal Transduction
Developmental Networks
Towards Individuality in computer systems

The problem

Current commercial systems do not adapt do not allow for individual user preferences, fix business processes and limit organisational development.
How do we develop adaptive systems which:
Are robust and conserve core business functionality while
Adapting to organisational changes,
Are capable of self-assembly in response to requirements,
Are adaptable to individual needs and express individuality within defined business constraints?

The source of models

Evolution
Population Genetics
Molecular Biology.
Systems Biology
Neuroscience

Specifically:

Molecular structure, molecular genetics,
Cell development, Cell communication

How do functional biological units form?
How does the genome relate to the phenome?

These models may give some clues on alternative approaches to programming computer systems which are

Component-based
Allow self assembly
Define protocols of interaction rather than any detail processing
Allow emergent functionality
Shape that emergent functionality to produce the desired individual system.

Problem:

Lower number of protein genes than anticipated:
Yeast 6200
Drosophila 12-14000
Human 30000

How can such low numbers lead to such high developmental complexity?
Alternative splicing will increase the protein repertoire

Mice and men sharing 99% of protein coding genes in common,

Of 3,000,000 sequence differences per hapliod genome between individual humans, only 10,000 0.3% occur in protein-coding sequences and mostly these are silent third base changes.

Phenotypic diversity may result from

Non-coding RNA networks (Mattick)

Protein - protein interaction networks which may be self-re-wiring (Fontana)

Cis-acting gene promotor/enhancer/repressor networks which control temporal development. (Davidson)

These interacting networks provide layers for phenotypic expression on top of the genomic layer.

They add informational value

Individuality then emerges from regulatory networks.

Non-coding RNAs

75% of transcripts
Intronic and non-protein-coding RNA constitute a majority of genomic output.
Correlation between intron density and developmental complexity
Developmentally regulated
High sequence complexity
In some cases conserved over large evolutionary distances.
But most introns are less conserved: 'wobble', variation and individuality.
May be involved in developmental regulation

A kind of soft wiring.

Some are intronic sequences.
Alternative splicing signal short and located as intron- exon boundaries.
Non-coding RNA is processed through pathways.
Clearly have functional activity:
Lin-4 lin 7 in C. elegans controlling developmental timing thorough RNA-RNA interactions.

Non-coding RNAs may be involved in:

Regulation of chromatin architecture
Gene silencing
Chromosome inactivation
Co-suppression

Mattick suggests that introns and non-coding RNA are not evolutionary junk, but form the primary control architecture underpinning eukaryotic differentiation and development.

Non-coding RNA networks may allow a greater amount of variability than protein networks. Hence limited individuality can be expressed with a stable architecture.

Differentiation of a sufficient critical mass to give rise to speciation could arise from cumultative changes in the much flexible non-coding RNA reaching a cusp or edge of chaos at which a bifurcation occurs which may become fixed as a species if the environment is right.

Phenotypic and individual characteristics may be seen as emergent phenomena, resulting from the added informational value derived from interactive, dynamic molecular networks.

Signal Transduction networks.

Molecular signals - hormonal effects, developmental signals are transmitted into cells through receptors are the cell wall.
Molecular signalling networks regulate cellular responses.
An extra cellular signal binds to a receptor and activates a signalling pathway.

Dimer molecules at cell membrane act as signal transducers

When the signal arrives, conformational changes occur inside the membrane
Conformational changes trigger off kinase activity.

There will be a repertoire of downstream targets within the network.
Which target is affected will depend on concentrations of signalling components.

Concentration changes may 'rewire' the network.

Hence the control network is dynamic, different routes being taken depending on concentration changes in components.

Signal Transduction Mechanisms

Conserved methods and basic mechanisms
Amplification cascades
Networks co-ordinating through messaging
Recognition, interface control, self-non-self.
Feedback control providing robustness
Self-tinkering
Repair mechanisms

Regulatory Networks for Development

Genes encode transcription factors
Cis-regulatory elements control these.
Each element receive multiple inputs form other genes in the network.
Operative cis-regulatory elements produce new and more refined spatial patterns
Control system as elegantly organised complex information processing devices.
Spatial triggers are signalling ligands produced by other cells.

Sea Urchin Endo16 regulatory system

Large polyfunctional protein secreted into embryonic and larval midgut
Early embryo -1 throughout mesoderm
2. throughout gut
3. only in midgut

Two modules
Nine sequence-specific transcription factors
Linear amplification
Intermodule switch
Detection of input thresholds
Logic operations

First stage regulatory network

Up to 24 hours
40 genes
Evolution of body plans occurred by changes in genomic programs for development of these plans
Change in regulatory networks
Patterns of regulatory interaction that are successively overlain with new regulatory pattern.

Individuality

Arising from interactions in control networks.

Emergent effects arising from complex interactions

Wobble, oscillations, variation permitted within a conserved overall control network.

Biology at the system level

Gene expression generates layers of interaction through complex, dynamics and self-evolving networks which are free to vary and generate emergent structure and behaviour within semi-fixed biological boundaries.

Obtaining Individuality in Computer Systems

Layers of complex control networks
Data
Interfaces
Application
Between applications
Over wide area networks.

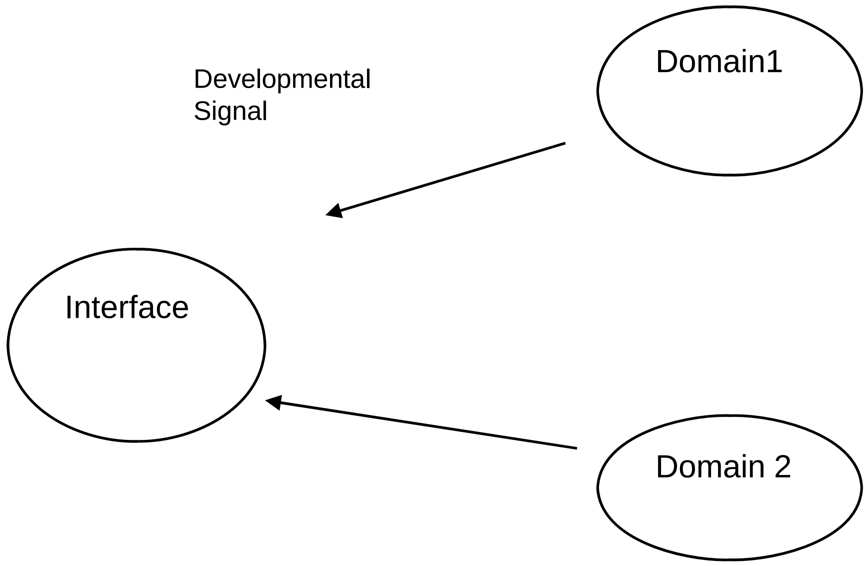
Elements which might exhibit individuality

Interface
Data
Data support architecture
Processing

Creating an evolvable architecture

Development of interaction networks

developmental
operational
evolving (environmental feedback)


Developmental
Signal
Domain1
Interface
Domain 2

Evolvable Interface Architecture

Structural units
Control networks
- Structuring
- Dynamic
- Feedback
- External stimulus

Signal Transduction Protocols

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