Open-Ended Evolution workshop, ECAL 2015
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Normalised evolutionary activity statistics and the need for phenotypic evidence

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1. Key concepts concerning open-ended evolution

From the Artificial Life XI (2008) theme on Open-Ended Evolution:

"This theme addresses the question of how to design and construct an artificial evolutionary system (in software or a physical medium) in which ***new adaptive traits continue to evolve*** over prolonged periods, without encountering a stopping point, and where there is a demonstrable sustained ***increase in the maximum complexity*** of organisms, ecosystems or behaviours."

http://web.archive.org/web/20090420042131/http://alifexi.wikispaces.com/Theme+-+Open-Ended+Evolution

2. A model that produces open-ended evolution?

A. D. Channon, Unbounded evolutionary dynamics in a system of agents that actively process and transform their environment, Genetic Programming and Evolvable Machines 7(3): 253–281, 2006. doi:10/b74rxr
http://www.channon.net/alastair/papers/channon_ad_gpem.pdf

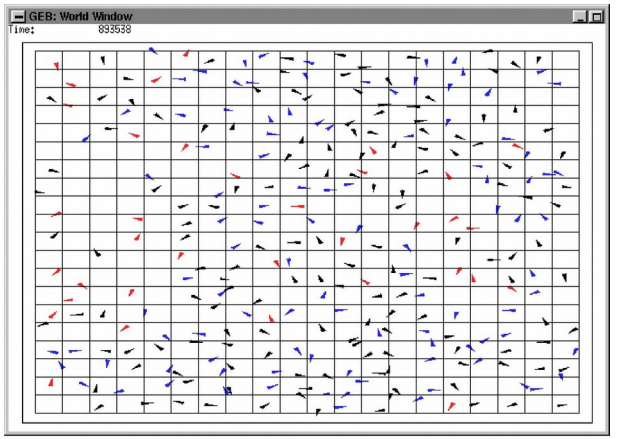
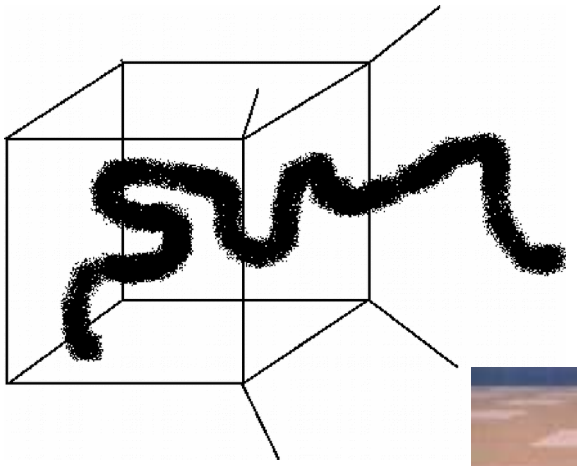
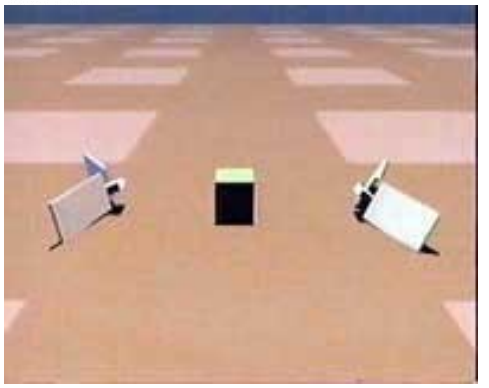


Figure 2: The experimental world (Geb).

- Based on Harvey's ~1997 SAGA framework for incremental artificial evolution





- but with coevolutionary feedback (cf. Sims 1994)

  arising, rather than being specified ('get cube'), via
- biotic selection rather than abiotic fitness functions.

See the paper above for details.

3. Quantitative and empirically operational measures

Normalised evolutionary activity statistics, based on Mark Bedau et al.'s work; see paper on the previous slide for details and Stout and Spector's validation of the modified "ALife Test".

Real run's component activity increment.

$$\Delta_i^{\mathrm{R}}(t) = \begin{cases} 1 & \text{if component } i \text{ exists} \\ & \text{in the real run at } t \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

Shadow's component activity increment.

$$\Delta_i^{\mathrm{S}}(t) = \begin{cases} 1 & \text{if component } i \text{ exists} \\ & \text{in the shadow at } t \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

Normalised component activity increment.

$$\Delta_i^{\mathrm{N}}(t) = \Delta_i^{\mathrm{R}}(t) - \Delta_i^{\mathrm{S}}(t) \tag{9}$$

Normalised component activity.

$$a_i^{\mathrm{N}}(t) = \begin{cases} \sum_{\tau=0}^{t} \Delta_i^{\mathrm{N}}(\tau) & \text{if component } i \text{ exists} \\ & \text{in the real run at } t \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

Normalised diversity.

$$D^{\mathrm{N}}(t) = \#\{i : a_i^{\mathrm{N}}(t) > a_0^{\mathrm{N}}\} \tag{11}$$

Normalised total cumulative evolutionary activity.

$$A_{\mathrm{cum}}^{\mathrm{N}}(t) = \sum_{i:\ \substack{\text{component i exists} \\ \text{in the real run at t}}} a_i^{\mathrm{N}}(t) \tag{12}$$

Normalised mean cumulative evolutionary activity.

$$\bar{A}_{\mathrm{cum}}^{\mathrm{N}}(t) = \frac{A_{\mathrm{cum}}^{\mathrm{N}}(t)}{D^{\mathrm{R}}(t)} \tag{13}$$

Normalised median cumulative evolutionary activity.

$$\tilde{A}_{\mathrm{cum}}^{\mathrm{N}}(t) = \operatorname*{Median}_{i:\ \substack{\text{component i exists} \\ \text{in the real run at t}}} a_i^{\mathrm{N}}(t) \tag{14}$$

Normalised new activity per component.

$$A_{\mathrm{new}}^{\mathrm{N}}(t) = \frac{1}{D^{\mathrm{R}}(t)} \sum_{i:\text{component i 'new'}} a_i^{\mathrm{N}}(t) \tag{15}$$

Aside: The question of whether or not OEE can be the cause of increasing maximal individual (or group or system) complexity is very interesting. It also highlights that complexity should not be included in a definition/measure/test for OEE: this is a related but different concept.

4a. Empirical results

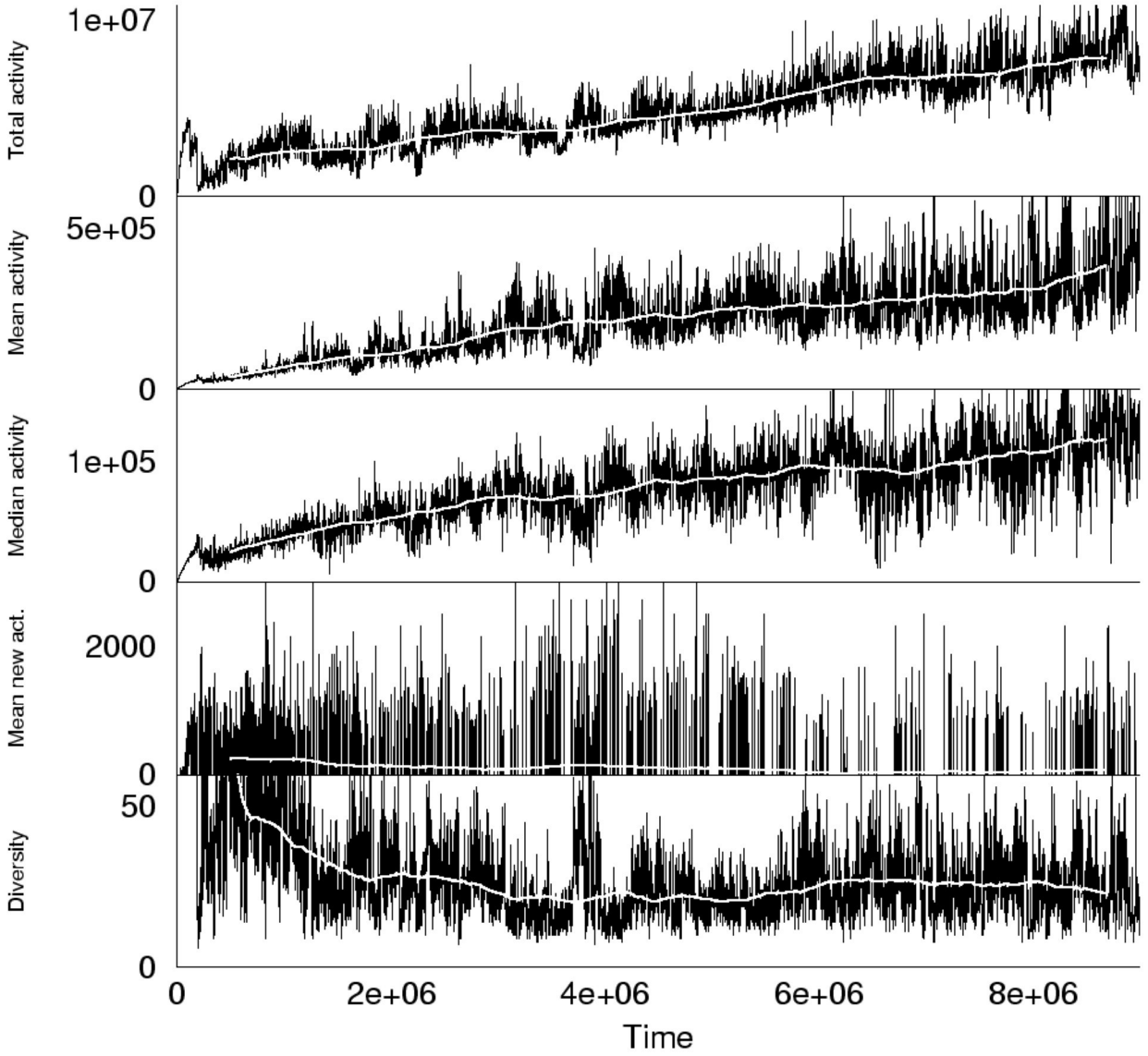


Figure 5: Normalised total activity, normalised mean activity, normalised median activity, normalised new activity, and real diversity. Running averages are shown in white.

However ...

4b. From empirical results to future milestones

- Certainty in a definition or classification scheme can only come about through its application to a range of evolutionary systems.
  - And the test may need to be refined: *What is lacking from a system passing the test (and so from the test) that we would like to require?*

- One significant weakness can be identified in Geb: it becomes difficult (impossible in practice) to understand or even identify novel behaviours as they emerge.
  - With relatively simple agents, we can analyze their controllers (programs, neural networks or other) directly to determine the resulting behaviours. But as the complexity of evolved controllers increases, this becomes infeasible, especially when using neural controllers. We can only observe the resulting behaviours and attempt to identify innovation.

- The logical aim is therefore to develop future systems such that behavioural descriptions are as easy to generate as possible, probably by constructing the systems such that behaviours will be transparent to human observers.

4c. On artefacts and behaviours

Examples of artefacts:

- Physical structures of bodies in a Creatures-like environment
- Lost copy loops in Tierra
- Matching I&O channels in neurocontrollers in Geb
- Potentially hierarchical structures (CA, Artificial Chemistries?)

These only really make sense when paired with descriptions of corresponding behaviours. So structural artefacts are interesting but not as central as behaviours.

Examples of behaviours:

- Creatures-like: crawling, walking, pushing, manipulating, following, fighting, fleeing, mimicking, ...
- Tierra: rapid copying, host, parasite, …
- Geb: following, reproducing with same pseudo-species, killing non-same, group-level motion patterns, rapid turning by non-same within these
- Potentially hierarchical behaviours (emergent development, symbiosis, …)

For increasingly complex behaviours, an environment similar to our own, e.g. with simulated 3D physics, would make the task of observing novel behaviours easier (cf. Tierra, Geb, PW).

5. Critical future research milestones

- More systems with an OEE classification from normalised evolutionary activity statistics.
  - only with these can we refine our test/definition of OEE and learn more about OEE-derived Life As It Could Be.
  - I would like to see many more. The test is easy to apply.

- Evidence of complex artefacts or behaviours arising from evolutionary changes (rather than from a very small number of mutations from a hard-coded ancestor).
  - *We have not <u>seen</u> these yet!* Evidenced by phenotype, not statistics.

  Normalised evolutionary activity statistics (and thresholds), novelty metrics on behaviour spaces, and complexity measures, could play a part in identifying when and in which individuals new artefacts or behaviours have evolved; and in understanding them, for example through comparing those individuals with a trait to those without.

- Evidence of non-trivial *long (evolutionary) sequences* of evolved artefacts or behaviours.
  - *We have not <u>seen</u> these yet!*
  - Preferably from systems that achieve a classification of OEE but let's take what we can get. For example Tierra did better than Geb here w.r.t. observations.
  - What is the longest known sequence of evolved artefacts/behaviours in ALife?

- Preferably all three together.