Further Investigations into Indefinite Scalability in Geb

Alastair Channon[1]

[1]School of Computing and Mathematics
Keele University
a.d.channon@keele.ac.uk

Abstract

This extended abstract updates and extends work presented at The Second Workshop on Open-Ended Evolution (OEE2). The two intervening years have allowed runs to complete with worlds (and maximum population sizes) four times the previous size, so now up to sixteen times the original system's size and again with up to eight times the original system's maximum number of neurons per individual.

The work aims to answer two related questions: can a (possibly) open-ended evolution (OEE) system such as Geb generate an unbounded increase in maximal individual complexity? and is diversity in Geb indefinitely scalable?

Considering the relationship between diversity and complexity leads to the general idea that complexity at one level of analysis can be considered as the diversity of components at the level(s) below. Thus the two questions reduce to one.

The notion of unbounded diversity is criticised for finite systems (including nature), and Ackley's concept of indefinite scalability is employed to give a more precise notion for this.

Indefinite scalability in maximum individual complexity (which would imply indefinite scalability in diversity) is tested for in Geb by varying two parameters: the hard-coded limit on the number of neurons an individual can have, and world length, which gives a bound (length squared) on population size. The combined (previous plus new) results are first reported along the previous lines. Then additional analysis, made possible by the new results, is given of the results when scaling both world length and maximum number of neurons per individual, together.

The results show maximum individual complexity to be asymptotically bounded when scaling the maximum number of neurons per individual alone but indicate that it is indefinitely scalable, or at least scalable to the extent tested so far (with runtimes in years and billions of reproductions per run), when scaling both the maximum number of neurons per individual and world length together.

Finally, the additional analysis raises interesting new questions and lines of thought about the feasibility of achieving complex results within an open-ended evolutionary system, which I hope to discuss at the OEE3 workshop.

Diversity and Complexity

One of the most interesting questions that OEE systems can address is whether or not OEE can be the cause of an unbounded increase in maximal individual (or group or system) complexity. This, of course, requires a definition of complexity; and that our definition of OEE does not already include ongoing growth of complexity (Taylor, Bedau, Channon et al. 2016), which would prevent us from being able to address (or even ask) this important question.

One unsatisfactory general measure of complexity is the number of components in an entity. A more satisfactory general measure of complexity is the number of different components, sometimes referred to as the diversity of components. The number of different components is still not a very satisfactory measure of complexity, just as it is not a very satisfactory measure of diversity, but this does lead us toward the general idea that complexity at one level of analysis (e.g. individual; species; or system) can be considered as the diversity of components at the level(s) below (e.g. genes; genes or individuals; genes or individuals or species). The same desirable tweaks to discount redundancy (e.g. to count only adaptive components, measure information content, …), and to include behaviours and interactions as well as artifacts, apply to both.

Unbounded Diversity???

In Bedau et al.'s classification of long-term evolutionary dynamics, the class of systems with unbounded evolutionary dynamics is divided into subclasses: (a) those with unbounded diversity of components but bounded adaptive success (cumulative evolutionary activity, based on adaptive persistence) per component; (b) those with bounded diversity but unbounded adaptive success per component; and (c) those with unbounded diversity and unbounded adaptive success per component.

Yet, while adaptive success per component can be truly unbounded (if measured based on adaptive persistence and over unbounded time), the diversity of adaptive components (both the number of different components per entity and the diversity of entities) is necessarily bounded: in artificial systems by unavoidable physical limits such as computer memory, and in nature (whether considering the biosphere or the Universe) again by physical limits such as number of atoms. A claim of unbounded diversity in the biosphere is really a claim that diversity is not practically bounded, or that it has not reached the upper bound yet. A more precise notion than "unbounded" diversity (of entities or of adaptive components per entity) is needed.

Indefinite Scalability

Ackley's concept of *indefinite scalability*, “defined as supporting open-ended computational growth without requiring substantial re-engineering” (Ackley 2014) now enables us to address this. The key criteria for indefinite scalability is that should an upper bound be reached, increasing the values of physical limitations (such as available matter, population size or memory) should enable an unbounded sequence of greater upper bounds to be achieved (after sufficient increases in the limitations); in the case of diversity, of greater upper bounds on diversity.

However, it is not possible (in finite system time) to establish that a metric (for example a measure of adaptive success per component) is truly unbounded. And it is not possible (over a finite number of increases in system parameter(s)) to establish that a metric (for example a measure of diversity) is truly indefinitely scalable. Further, an increase in parameter(s) may require a longer system (run) time before a greater scale (higher value metric) is achieved. Claims about systems can, though, be expressed and evaluated in terms such as a metric (for example a measure of adaptive success per component) increasing apparently without bound *up to* a certain system time (or number of generations, etc.); or a metric (e.g. diversity) increasing *up to* certain value(s) of system parameter(s) being reached, where it was necessary to increase these to establish increases in scale (e.g. of diversity) over successive runs.

Testing for indefinite scalability in Geb

This work investigates whether or not the maximum complexity of an individual is indefinitely scalable in Geb (Channon 2001, 2003, 2006), where an individual's complexity is measured as the diversity of components in it. Note that if the diversity of components in an individual is indefinitely scalable, then so is the diversity of components in the system, so the question of which subclass (a, b or c) Geb is in is also being addressed.

As in previous work analysing Geb's long-term evolutionary dynamics, a component is, in loose terms, an active gene: a gene involved in the agent's neural development; see (Channon 2006) for details. So, here, an individual's complexity is measured as the number of different genes involved in its neural development.

Two parameters cause diversity to be bounded in Geb: 1. a hard-coded limit on the maximum number of neurons an agent can have; and 2. the 2D world's length L, as there can be at most L^2 individuals in the population at any one time. These are the two parameters that are scaled. 20 runs were carried out for each combination (value pair) of these parameters, and the average (over 20 runs) maximum individual complexity recorded and graphed using a running average of length 100 to reveal underlying trends.

Results and Conclusions

Maximum individual complexity appears to be asymptotically bounded when scaling (just) the maximum number of neurons per individual (figure 1). Likewise, maximum individual complexity appears to be asymptotically bounded when scaling (just) world length (figure 2).

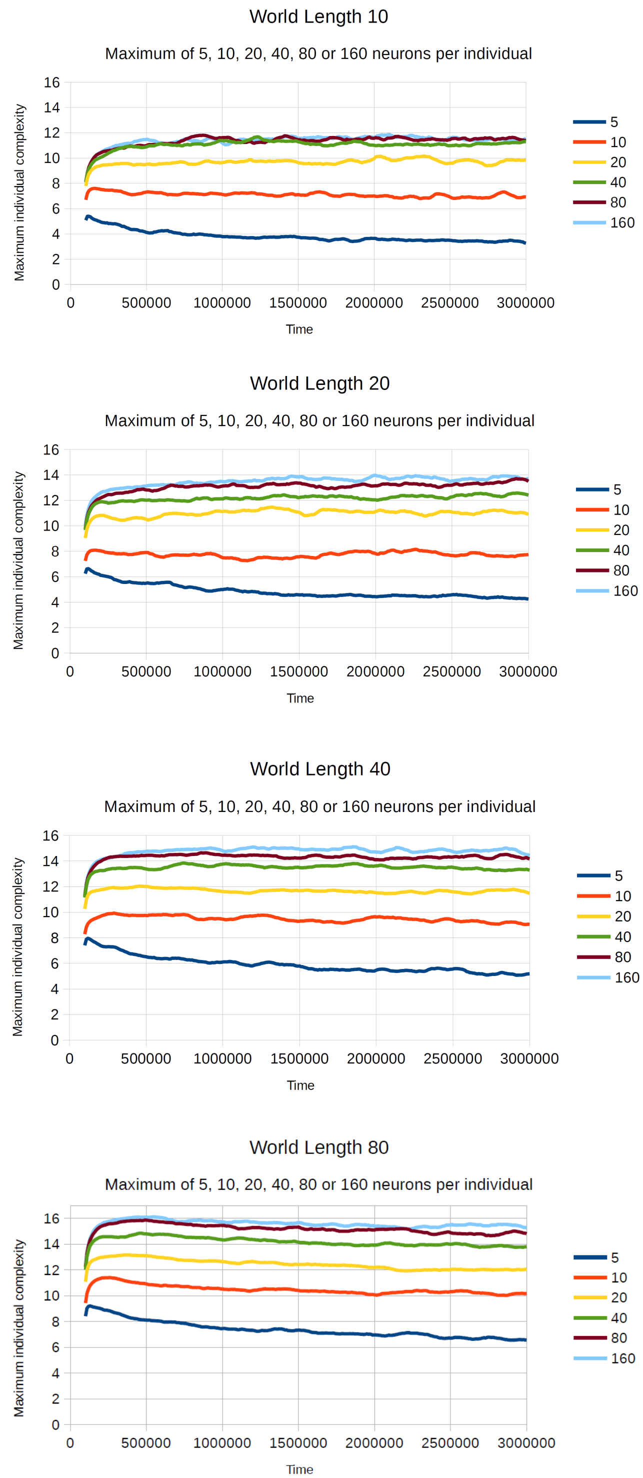

Figure 1: **Results when scaling the maximum number of neurons per individual (at different world lengths).**

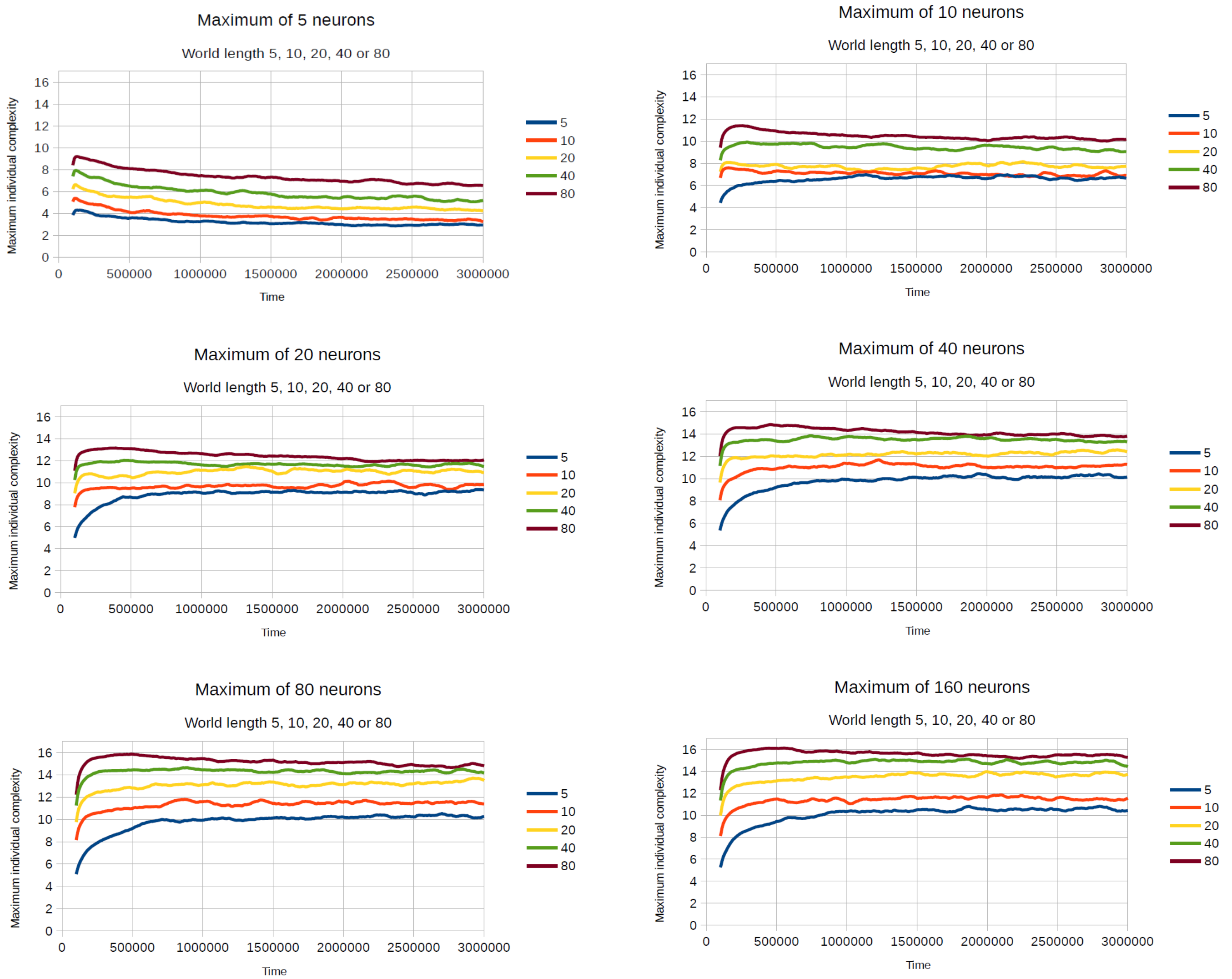

Figure 2: **Results when scaling world length (at different maximum number of neurons per individual).**

Figure 3 gives the first indication that maximum individual complexity may be indefinitely scalable, or at least scalable to the extent tested so far (with runtimes in years and billions of reproductions per run), when scaling both the maximum number of neurons per individual and world length together.

Figure 4 demonstrates this more conclusively. It shows maximum individual complexity raised to the powers 1, 2, 3, 4 and 5, and then averaged over time steps 2 million to 3 million and over 20 runs, with world lengths scaling in conjunction with the maximum number of neurons per individual as shown. The fitted lines shown with coefficients of determination are the result of simple linear regression on the logarithm of scale (see horizontal axes). The world lengths here are 10 (half the original system's value for this parameter) and above, and the maximum numbers of neurons per individual are 20 (the original system's value for that parameter) and above. Within these ranges maximum individual complexity is found to be approximately normally distributed (more closely so as as world length and therefore maximum population size increases), avoiding the edge effects that arise from smaller values of these parameters.

According to this analysis, the only bounds to complexity and diversity are time and computer memory (similar to nature) and Geb is in subclass c.

However, it is not clear from figure 4 what power of maximum individual complexity scales linearly with the logarithm of the scale parameter. The value of this exponent has significant implications for the prospects of achieving complex results from an open-ended evolutionary system *within feasible timescales*. At the time of writing I am still thinking through what the implications are; I hope to discuss them at the OEE3 workshop.

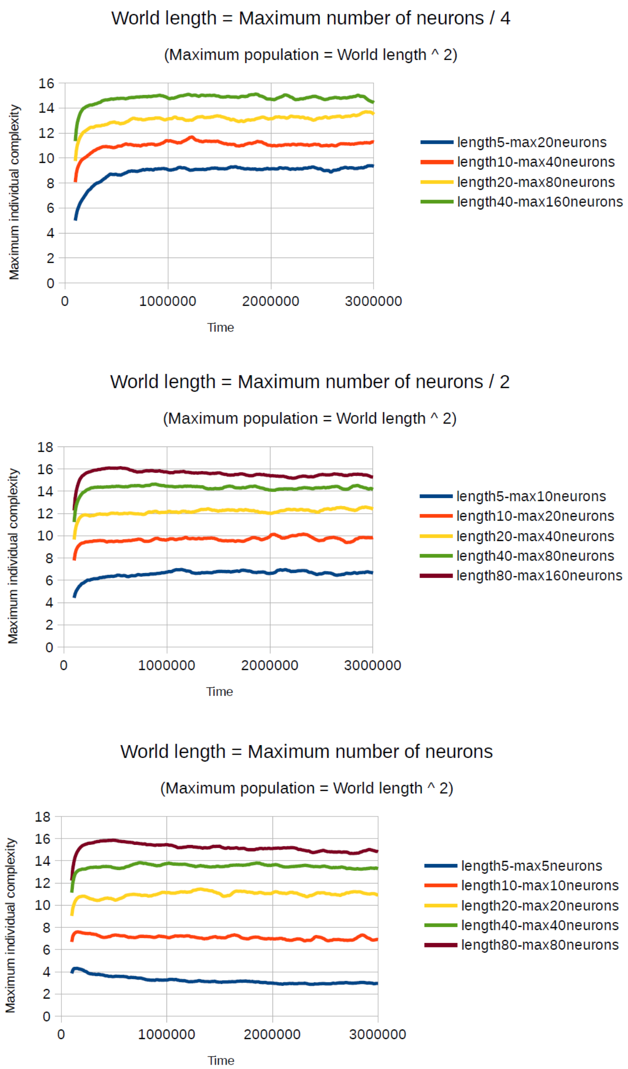

Figure 3: **Results when scaling both world length and maximum number of neurons per individual, together.**

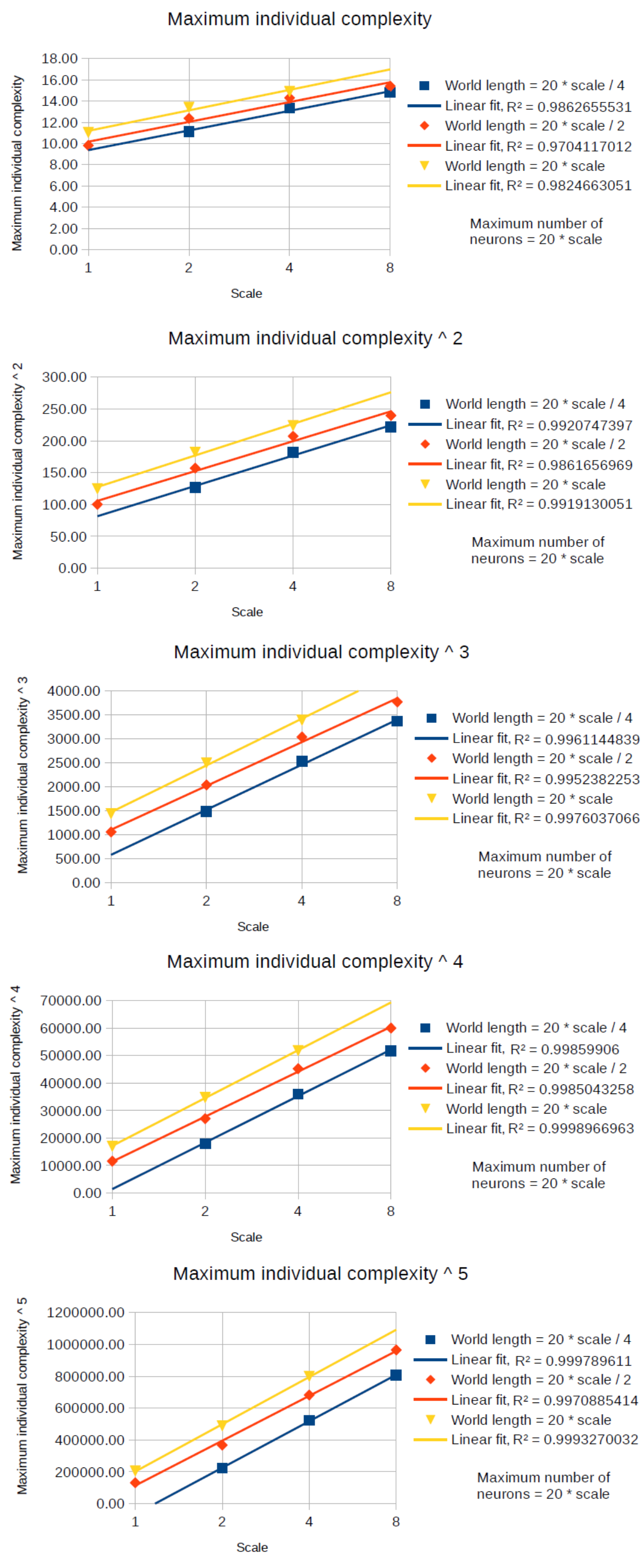

Figure 4: Scalability of maximum individual complexity, raised to the powers shown and then averaged over time steps 2 million to 3 million of 20 runs.

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