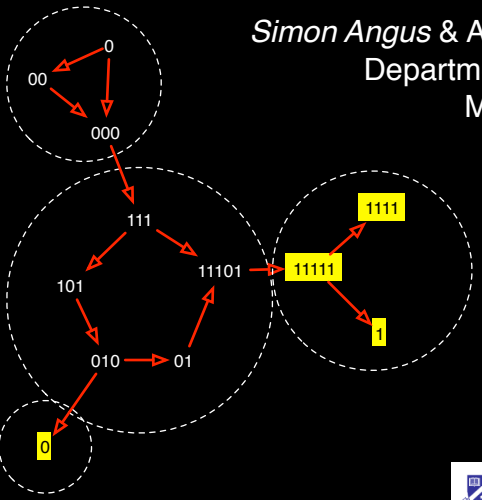
The Bit-Economy: an artificial model of specialisation and open-ended technology growth

Simon Angus & Andrew Newnham
Department of Economics
Monash University



SYDNEY AGENTS

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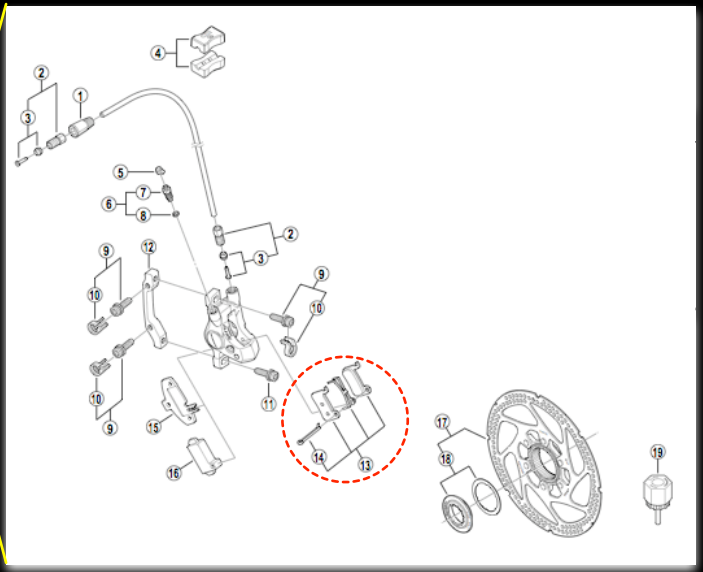
An example ...

An example ...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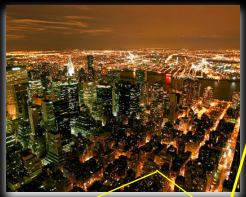

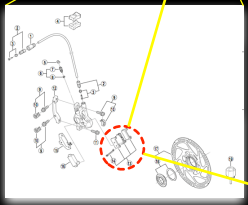

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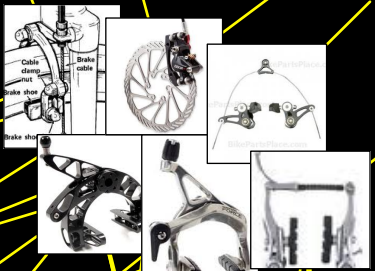
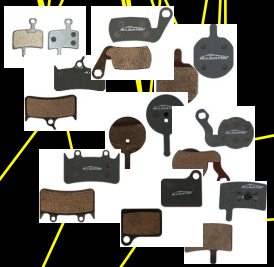
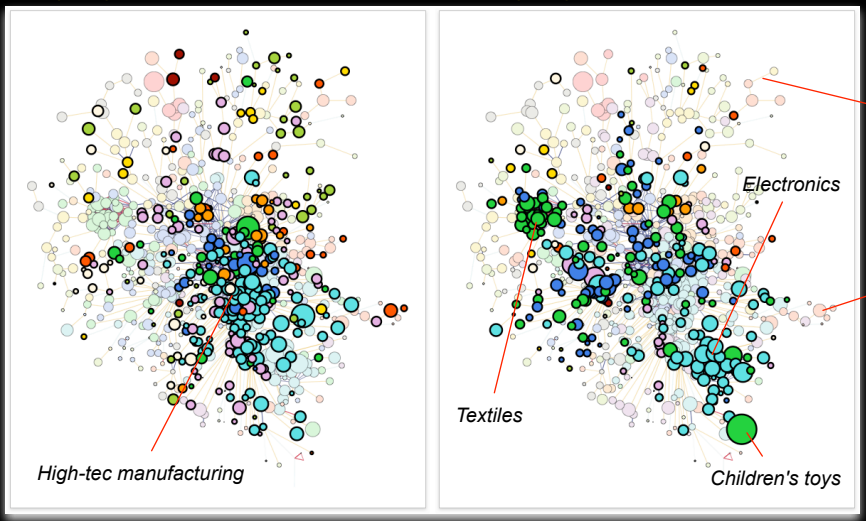
The technium i: multi-scaled, complex, open-ended, modular, (alive?)





Kevin Kelly 2010: "The Technium"

The technium 2: product space



'Economic Complexity Observatory' (MIT)

See: Hidalgo & Hausmann, 'The building blocks of economic complexity', PNAS 106(26):10570-10575

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Technology ...

... is an evolutionary, dynamic, process, with abrupt changes

"[W]hat we are about to consider is that kind of change arising from within the system which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitesimal steps. Add successively as many mail coaches as you please, you will never get a railway thereby." (Schumpeter, TTED, 1934)

"The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process." (Schumpeter, CSD, 1945)

"[The process] must be seen in its role in the perennial gale of creative destruction; it cannot be understood on the hypothesis that there is a perennial lull." (Schumpeter, CSD, 1945)

TTED: The Theory of Economic Development

CSD: 'Capitalism, Socialism & Democracy'

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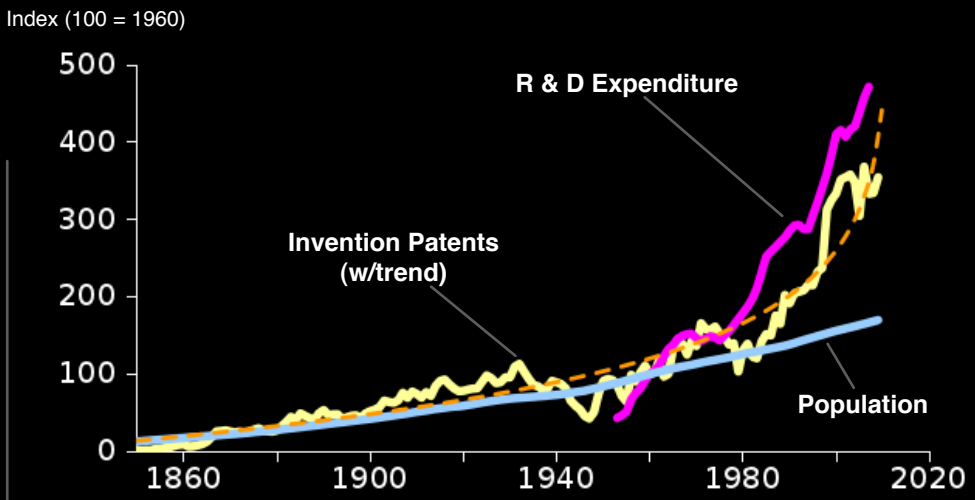
US data on patents, population & R&D



Patent data: US Patents and Trademark Office (http://www.uspto.gov/web/offices/ac/ido/oeip/taf/h_counts.htm)
R&D data: US National Science Foundation, Division of Science Resources Statistics (http://www.nsf.gov/statistics/infbrief/nsf08317/
Population data: Angus Maddison (http://www.ggdc.net/maddison/Maddison.htm)

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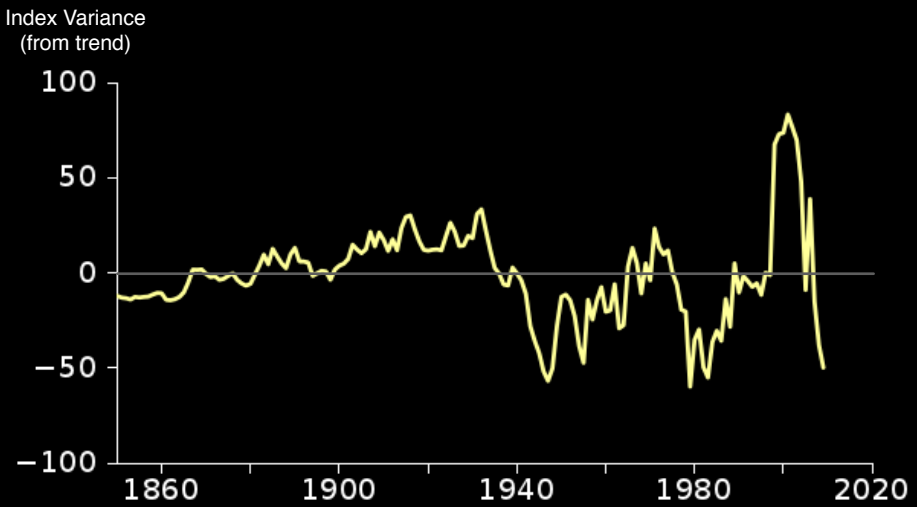
De-trended patent time-series



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'Economic biology' or 'mechanical analogies'

The Mecca of the economist lies in economic biology ... But biological conceptions are more complex than those of mechanics; a volume on Foundations must therefore give a relatively large place to mechanical analogies, and frequent use is made of the term 'equilibrium' which suggests something of a static analogy.

(Alfred Marshall, Principles of Economics, 1948, p.xiv)

Technology (behind the economy)...

Smith on the division of labour

It is the great multiplication of the productions of all the different arts, in consequence of the division of labour, which occasions, in a well-governed society, that universal opulence which extends itself to the lowest ranks of the people. (Adam Smith, Wealth of Nations, 1776)

Lucas on growth

technology

"Once one starts to think about ~~economic growth~~, it is hard to think about anything else."

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Technology is ...

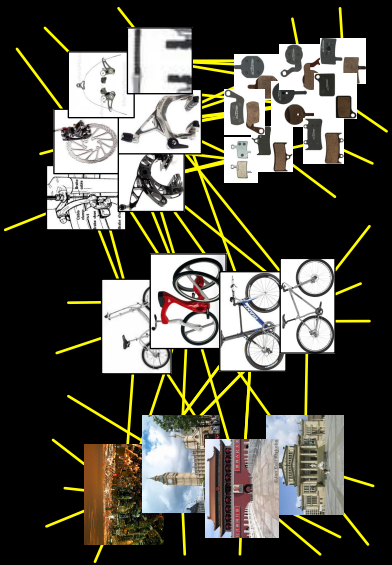
modular: a device is made up of sub-devices

co-dependant: a device needs inputs (materials) and uses (demands)

multi-scaled: 'technology' can be resins, disc-pads, ..., economic systems

perpetual local search (diversity, selection): new devices are formed by modifications of old devices

coordinated (timely): materials and demands must both exist in time



"Standard theory"

Growth models

Neo-classical models (e.g. Solow)

Technology as productivity

Constant percentage growth year/year

Exogenous, passive in explaining growth

Endogenous Growth Theory (e.g. Romer)

Technology as 'ideas'

Produced by constant fraction of population, fraction of capital (R&D

Rate of ideas and growth rate float

New theory

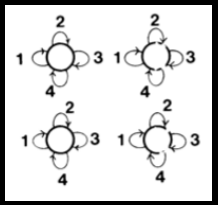
New-classical theory

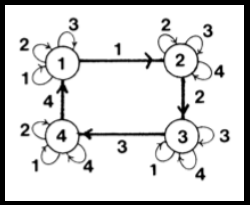
Specialisation & the Division of Labour (e.g. Yang 1991, JPE)

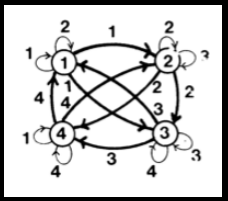
Technology is organisation of the economy

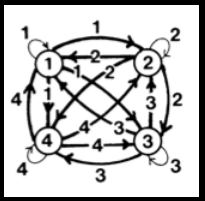
Depends on transaction costs, extent of market

Returns to specialisation imply large, complex economies are more productive









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Technology back on the agenda (why?)

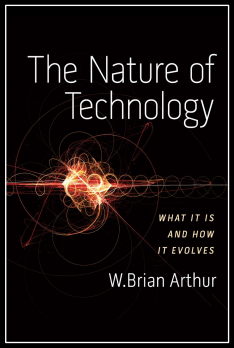
PNAS

Role of design complexity in technology improvement

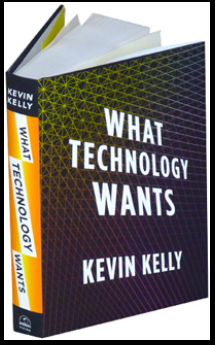
James McNerney[a,b], J. Doyne Farmer[a,c], Sidney Redner[a,b,d], and Jessika E. Trancik[a,e,1]

[a]Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501; [b]Department of Physics, Boston University, Boston, MA 02215; [c]Libera Universitá Internazionale degli Studi Sociali, Guido Carli, Viale Pola 12, 00198 Rome, Italy; [d]Center for Polymer Studies, Boston University, Boston, MA 02215; and [e]Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA 02139

May 20 2011 (online)



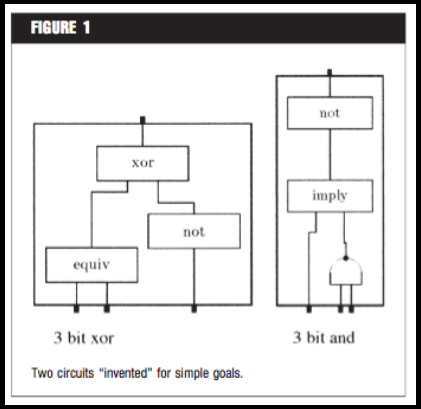
Jan 2011



2010; EconTalk Nov 2010

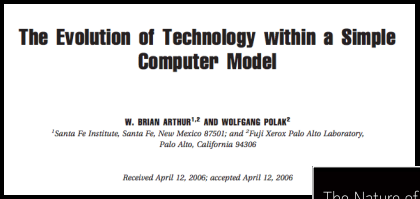
"The Technium"

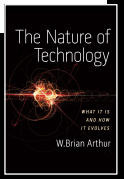
Arthur, 2006

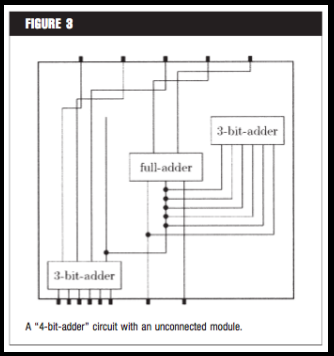


A device is a combination of basic components

Local search: recombination of devices
Devices are tested by their **look-up table**



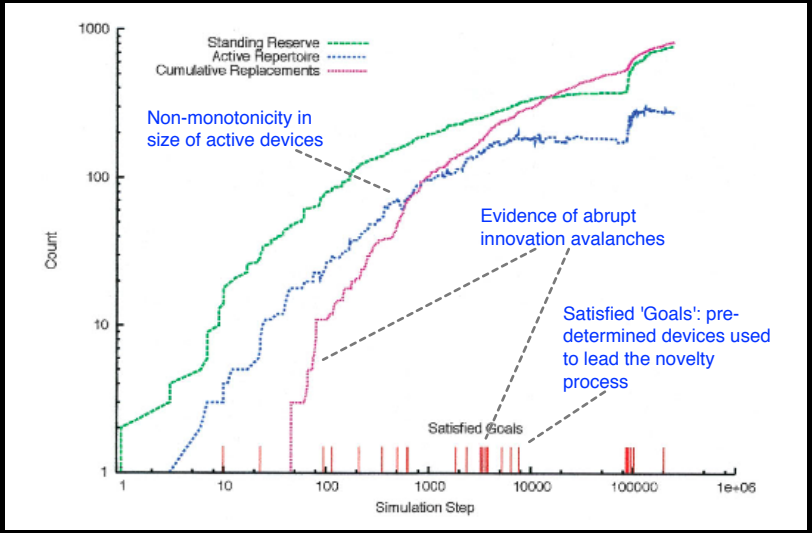




Devices can be combined into larger devices

Arthur, W. B., & Polak, W. (2006). The evolution of technology within a simple computer model. *Complexity, 11*(5), 23-31. doi:10.1002/cplx.20130

Arthur, 2006



A new device is accepted on the basis of its look-up table: how close is it to the desired binary table for the next technology step?

Arthur, W. B., & Polak, W. (2006). The evolution of technology within a simple computer model. *Complexity, 11*(5), 23-31. doi:10.1002/cplx.20130

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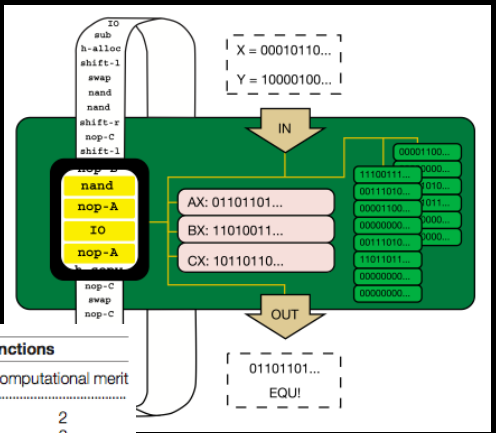
Lenski, 2003

Avida: the search for 'EQU'

The evolutionary origin of complex features

Richard E. Lenski*, Charles Ofria†, Robert T. Pennock‡ & Christoph Adami§

Input: binary strings



Computations achieved by micro-machine ('CPU', 'memory' etc.)

Output: binary string

Table 1 **Rewards for performing nine one- and two-input logic functions**

Function name	Logic operation	Computational merit
NOT	~A; ~B	2
NAND	~(A and B)	2
AND	A and B	4
OR_N	(A or ~B); (~A or B)	4
OR	A or B	8
AND_N	(A and ~B); (~A and B)	8
NOR	~A and ~B	16
XOR	(A and ~B) or (~A and B)	16
EQU	(A and B) or (~A and ~B)	32

Increasingly complex device requirments

Lenski, R. E., Ofria, C., Pennock, R. T., & Adami, C. (2003). The evolutionary origin of complex features. *Nature Materials*, *423*(6936), 139-144.

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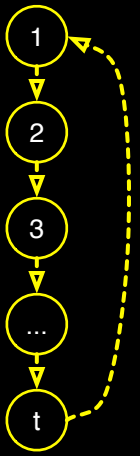
Padgett, 1996

Hypercycles of 'skills'

Exogenous feasible technology



Devices inhabit lattice

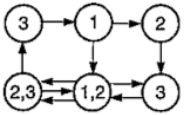
1	2	2	1	3
1,2	1	2	2	1,3
2	1	1,2	2	2
1	3	1	3	1
1,3	2	2,3	2	2

Reproduction of skills if matching with technium

Output technium structures

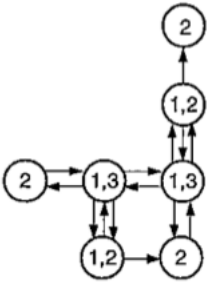
3) Run #3

23	23	23
47	54	29



1) Run #1

		18
		42
20	42	34
	20	23



Padgett, J. F. (1996). The emergence of simple ecologies of skill: A hypercycle approach to economic organization. *The Economy as an Evolving Complex System II.*

Towards a generative theory of technology

Components:

To keep: Modular, co-dependant, local search, coordinated, novelty engine

Truly generative: open-ended, self-directed, large (statistical) technium space, demand/supply criterion

Outputs:

Underlying growth mechanism: geometric

Time-series: abruptness, 'gales', volatility clustering

Network of technology (the 'technium'): clustering, cycles?

The Bit-Economy

Products: binary strings

0010111001 0011

011101 00 1

1111111 1011

String defines **complexity** of product

Devices: convert products into other products

0010111001 → 111111

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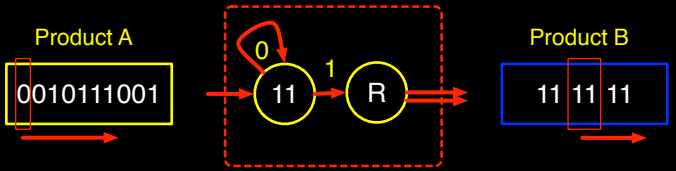
Devices: finite state automata (FSA)



Minimal output components

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Extenders

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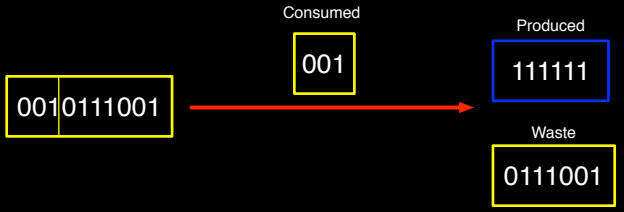
Reporter (finish)

R



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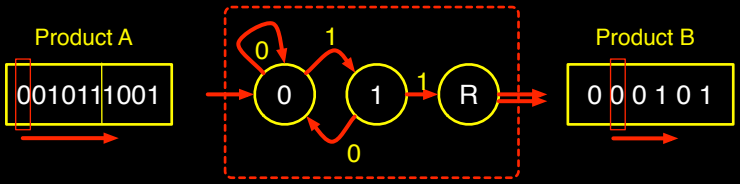
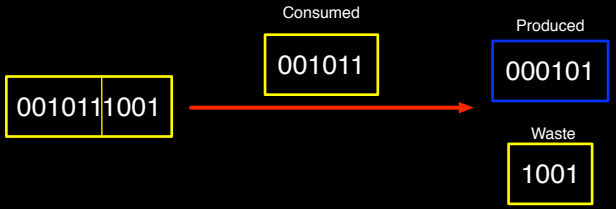
A more complex device (same input)





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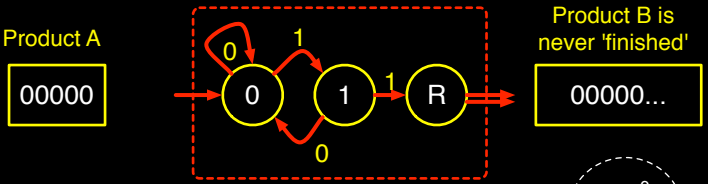
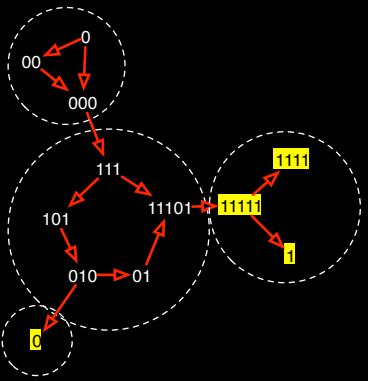
Devices must be compatible with an input



Viability constraint: new devices must 'work' with current technium, e.g. have at least one valid input in production, and that output be demanded (by another device)

Creative destruction: If a new device doesn't satisfy viability after T periods, it is deemed non-viable ... potentially causing other devices to become unviable in subsequent periods (a tech bubble).



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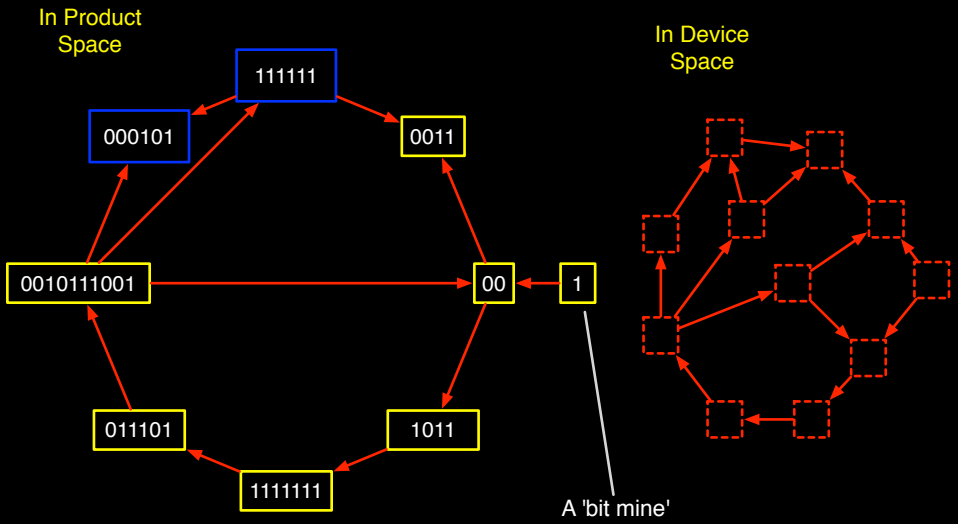
Reproducing the technium



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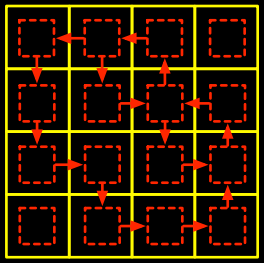
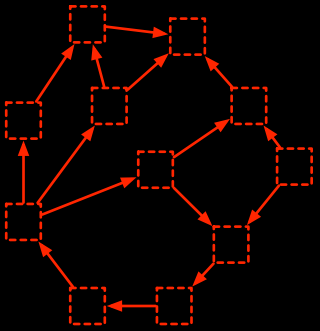
Device demand/supply

Novelty: FSAs can be easily 'mutated' to change one output bit type, or the configuration of states to create new devices

Computational Complexity: with a medium technium, testing device viability becomes computationally intensive (run device with all current products ...!)

Interaction constraint: Run initially on a lattice and test for viability with surrounding (4) neighbours. Add short-circuits later.





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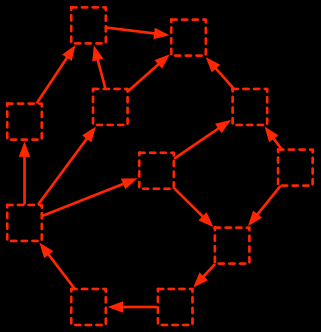
Advantages of the bit-economy

Very large device/product space: possibility for highly diverse economies to evolve in each run; path-dependence, and institutions will matter

'Virtually' open-ended search: no externally defined search targets -- technium can be built however it likes (almost). FSAs are very simple, but highly flexible (even a few states give rise to massive diversity).

Factor endowments & institutions: Allows the investigation of endowments (e.g. bit-mines), and institutions such as R&D support (periods for a non-viable device to be held), patent libraries (do devices ever become extinct?), trade (two evolved techniums -- what happens when we bring them together?),

Possibility for validation of the device/product network: Large enough space for growth, diversity, and evolving, dynamic network implies options for matching to existing product/patent data (even wealth / GDP/cap) options.



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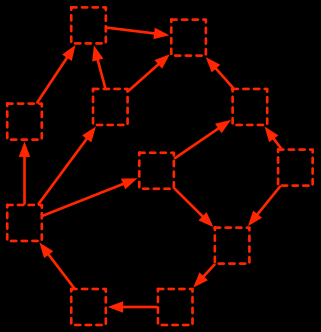
Challenges ...

'Cost of production': how to calculate this?

What if the problem is too hard (too open ended)? There are options to tune/reduce complexity with FSA state limits etc. .. Something to be aware of.

Does the lattice impose too big a constraint on matching/ viability? Options to relax this assumption and allow for broader connections ... but ... computational complexity!

... and many others ... (apart from the usual)