Technology and Combinatorial Evolution

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W. Brian Arthur
External Professor, Santa Fe Institute
System Sciences Lab, PARC
The Nature of Technology

WHAT IT IS AND HOW IT EVOLVES

W. Brian Arthur
Can there be a theory of evolution for technology?
Evolution’s two meanings:

Lineages alter their form – descent by modification

All organisms are related by ties of genealogy or descent from common ancestry
Darwin’s Mechanism

“It is the steady accumulation through natural selection of such differences, that gives rise to all the important modifications of structure.”

“Complex organ[s] … formed by numerous, successive, slight modifications”

Problem: *This doesn’t work for technology*
So if technology evolves, what is the mechanism?

We are looking for a mechanism of heredity in the origin of novel technologies – in invention
An observation

Technologies are constructed ... from existing technologies
Where do novel technological species — inventions — come from?
Ogburn’s Claim (1922)

"It would seem that the larger the equipment of material culture, the greater the number of inventions. When the existing material culture is small, embracing a stone technique and a knowledge of skins and some woodwork, the number of inventions is more limited than when the culture consists of a knowledge of a variety of metals and chemicals and the use of steam, electricity, and various mechanical principles such as the screw, the wheel, the lever, the piston, belts, pulleys, etc. The street car could not have been invented from the material culture existing at the last glacial period. The discovery of the power of steam and the mechanical technology existing at the time made possible a large number of inventions."
Invention is a process

Linking a need with the idea of some effect that will fulfill it
This poses problems and sub-problems. They too need the idea of some effect...

Result: A combination
Example: Gary Starkweather 1972

Problem: How to print images from a computer

Several possible principles
Possible principle: Use a laser to “paint” images on a Xerox drum

Sub-problems:

- Modulating the laser
- Moving the laser rapidly
- Use a mirror
The structure of invention

W. Brian Arthur

Santa Fe Institute, 1399 Hylo Park Road Santa Fe, NM 87501, USA

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Abstract

This paper explores the process by which radically novel technologies—ones such as radar, the turbojet, or the polymerase chain reaction—come into being. It shows that this process—"invention"—has a certain logical structure common to all cases. Invention is a process of linking some purpose or need with an effect that can be exploited to satisfy it. It may begin with a purpose or need for which existing methods are not satisfactory; this forces the seeking of a new principle (the idea of an effect in action). Or it may begin with a phenomenon or effect itself—usually a freshly discovered one—for which some associated principle of use suggests itself. Either way, translating this base principle into physical reality requires the creation of suitable working parts and supporting technologies. These raise their own challenges or problems, the solution of which may raise further challenges. As a result, invention is a recursive process: it repeats until each challenge or problem (and subproblem, and sub-subproblem) resolves itself into one that can be physically dealt with. It is challenging, usually lengthy, part-conceptual, and part-experimental.

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1. Introduction

Schumpeter famously divided technological change into "feverish" and "genius." He stressed that invention was a process. It was a process whereby novel technologies came into being as fresh combinations of existing ones. (Thurston in 1889 and Førland in 1894 independently developed the polymerase chain reaction, for example.) Then he went on to explain that when a new technology comes on the scene, it changes the nature of competition. It creates new problems and challenges; it changes the nature of the contest. He then went on to explain that the problems and challenges changes the dynamics of the contest, thereby creating the potential for further innovation.
Invention is a process of “finding” what’s needed for the purpose in what already exists
We can say …

Novel technologies are constructed from existing technologies …

These offer themselves as components—building blocks—for the construction of further technologies.
We can say better ...

Novel technologies are constructed from existing technologies and from capturing phenomena

... These offer themselves as components—building blocks for the construction of further technologies
The collective of technology is a vast ancestral network

that creates new nodes from existing (parental) ones

It is *autopoietic*: new elements build from existing ones

Complication builds from simplicity
Combinatorial Evolution

Technologies form a vast “chemistry” of elements, that in combination give rise to (make possible) further elements
This suggests an evolutionary algorithm

1. Start with a “soup” of elements
2. Form combinations (possibly at random) from this
3. If a combination is useful, encapsulate and preserve it
4. Add new combination to soup as a building block element
Could you get combinatorial evolution to work on a computer?

This would be difficult
Combinatorial Evolution in the Lab. An expt.

Idea

Create an artificial world in which technologies evolve indefinitely from previous ones. I.e. Allow the system to create technologies by combining previous technologies

The technologies will be logic circuits
An artificial world within the machine

Little agents in green eye shades

They have a wish list of “needs” for logic circuits to be potentially fulfilled

( eg. 2-bit EXOR, 4-bit EQUALS, 2-bit adder, etc)
How the experiment works

1. Start from one primitive element (a NAND gate) and a wish-list of needs (target logic purposes)
2. Make circuits by random combination of existing elements
3. Check to see if any needs are fulfilled
4. If so, these novel circuits become encapsulated and used as new building blocks
NAND:
the primitive element
NOT circuit
IMPLY circuit
Tech 20
1-bit adder
2-bit adder

1-bit adder-56

Full adder-327
Tech 33: And-3
3-bit adder
4-bit adder
Findings
After 250,000 steps

Quite complicated circuits have evolved:

- 8-way EXOR, 8-way AND, 4-bit EQUALS, etc.
- An 8-bit ADDER (16 inputs, 9 outputs).

This is one of $10^{177,554}$ possible circuits.
But these complicated technologies require intermediate steps

They require intermediate (simpler) technologies

... which only appear if there are intermediate needs

A Cambrian explosion?

After about 30,000 steps, sudden appearance of key circuits (enabling technologies) then quick use of these

- Full adder appears after 32,000 steps; 2, 3, 4-bit adders

quickly after that
The evolution is history dependent

New technologies build out of ones “discovered” earlier

So the order in which technologies are invented matters
Schumpeter’s Gales of Destruction

When a technology disappears (is replaced), a technology it used may have no further use. That tech then disappears ... etc.

Q. Are these gales “sand-pile avalanches”? I.e. Is the system at self-organized criticality?
Avalanches of destruction follow a power law
**Biological Evolution:**
Darwinian variation and selection
accumulation of incremental changes
But ... occasional combinations

**Technological Evolution:**
Combinatorial evolution
Abrupt, self-augmenting
With much Darwinian evolution once a technology exists
Some Remarks on Combinatorial Evolution
Darwin’s Evolutionary Algorithm

Start with a population that produces variations
Select differentially
New population produces further variations
Population diverges by steady accumulation of small changes
Combinatorial Evolutionary Algorithm

Start with some primitive building blocks
Make combinations
If useful embody as new building block
Add this to building blocks

The result is a library of functionalities, not single solutions
Combinatorial Evolution occurs in:

- Mathematics
- Various chemistries
- Construction of Programming Libraries
- Genetic regulatory networks
- The collective of technology
- Physical cosmos
Francois Jacob

“In our universe, matter is arranged in a hierarchy of structures by successive integrations. Whether inanimate or living, the objects found on earth are always organizations or systems. Each system at a given level uses as its ingredients some systems from the simpler level. ... The great diversity of vertebrates results from differences in the arrangement, in the number and distribution, of these few [building blocks].”
Combinatorial Evolution

Has a much bigger adjacent possible

New things can be made if they are ordered — reachable from previous ordered things

Possibly this is why the world is highly ordered
Summary

Technology does indeed evolve
The mechanism is not same as
Darwin's

Combinatorial evolution is widespread