GROWTH, INNOVATION, AND THE ACCELERATING PACE OF URBAN LIFE: ARE 21ST CENTURY CITIES SUSTAINABLE?

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ARE WE SUSTAINABLE?

ARE THERE QUANTITATIVE, PREDICTIVE LAWS OF LIFE?

CAN THERE BE A SCIENCE OF CITIES, COMPANIES AND SUSTAINABILITY?

WHAT CAN WE LEARN FROM BIOLOGY AND PHYSICS?
WE LIVE IN AN EXPONENTIALLY EXPANDING SOCIO-ECONOMIC UNIVERSE!!

1800 < 4% OF THE US POPULATION WAS URBAN

2011 > 80%

2006 > 50% WORLD’S POPULATION URBANISED

2050 > 75%

EVERY WEEK FROM NOW TILL 2050 OVER ONE MILLION PEOPLE ARE BEING ADDED TO OUR CITIES
Public sculptures cast in metal are being substituted with cheap plastic replicas to prevent them being stolen by thieves feeding the voracious appetite for commodities in China and India.

The Historic Houses Association said this weekend that many stately home owners were putting antique garden statues into storage and displaying plastic copies instead.

1 September 2011
Scaling of economics with energy use
TIME - 130 years

- Strong inflow of overseas capital
- Strong overseas investment, scrip shortage and property boom
- 1929 Crash
- British lending ceases
- Export prices collapse
- Industrial activity falls
- Many businesses close
- Start of 1914-18 War

- 1939-45 war
- Pearl Harbour
- USA enters war
- Oil found in Bass Strait
- 1960 credit squeeze
- Commodity prices recover, new mineral discoveries
- Industrial rationalisation

- Oil, mining & Poseidon booms
- Energy and Metal shares boom
- Industrial and Property boom. First labour government since 1949
- Start of Iraq War
- Iraq War speculation
- World economy slows
- World Share price collapse
- Bank credit fuels property boom

- China fuels resource boom
- September 11 Terrorist Attack on the World Trade Center
SOCIO-ECONOMIC ENTROPY!!
MASSIVE INCREASE IN KNIFE CRIME SURVEYS
NEED A SCIENCE OF CITIES

“GRAND UNIFIED THEORY OF SUSTAINABILITY”

ARE THERE UNIVERSAL, QUANTIFIABLE PRINCIPLES?

COMPLEMENT TO TRADITIONAL (QUALITATIVE) THEORIES AND MODELS
ARE CITIES AND COMPANIES JUST VERY LARGE ORGANISMS SATISFYING THE LAWS OF BIOLOGY?

WHY DO ALL COMPANIES DIE WHEREAS ALMOST ALL CITIES SURVIVE?
- METABOLISM
- GROWTH
- AGING/DEATH
- EVOLUTION
- SLEEP/REPAIR
- DISEASE/CANCER
THE SEARCH FOR UNDERLYING LAWS AND PRINCIPLES LEADING TO A QUANTITATIVE PREDICTIVE (COARSE-GRAINED) CONCEPTUAL FRAMEWORK

[ENERGY & RESOURCES (METABOLISM) vs. INFORMATION (GENOMICS)]
INTERSPECIFIC SIZE DISTRIBUTION

All species in a Malaysian Rainforest

\[ N = 62 \ D^{-2.07} \]

\[ N = 55 \ D^{-1.95} \]
SCALABILITY
RESILIENCE
EVOLVABILITY
GROWTH
Mammals vary in size by 8 orders of magnitude.

Shrew: 2g

Elephant: 2,000,000g

Blue Whale: 200,000,000g
Soybean Growth Stage Terms

- Emergence (VE): Hypocotyl pushes through soil surface.
- Cotyledons (VC): Unfolding endosperm of specialized seed leaves.
- 1-Trifoliate (V1): First node containing 3 leaflets of 1 full leaf.
- R6: Seed produced.
TIME - 130 years

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SLOPE = $\frac{3}{4} < 1$ SUB-LINEAR
Whole-organism metabolic rate ($B$) scales as the 3/4 power of body mass ($M$)

$$B \propto M^{3/4}$$

Hemmingson 1960
$B \propto M^{0.780 \pm 0.037}$
EXTRAORDINARY SYSTEMATIC ECONOMY OF SCALE (THE BIGGER YOU ARE, THE LESS NEEDED PER “CAPITA”)

SIMILAR SCALING HOLDS TRUE FOR ALL PHYSIOLOGICAL PROCESSES AND LIFE HISTORY EVENTS OVER THE ENTIRE SPECTRUM OF LIFE
Metabolic rate sets the pace of life. Small animals live fast and die young.

Heart rate scales as $-1/4$ power of body mass.
log_{10} W = (1.23 \pm 0.01) \log_{10} G - (1.47 \pm 0.04)

r = 0.998
Dependence of Prokaryotic Genome Length on Cellular Mass

- Non-photosynthetic Prokaryotes
- Cyanophyta

Slope = 0.24 +/- 0.02
Intercept = 9.4 +/- 0.2
NETWORKS!!!
Relation between number and size of branches within a tree
Fig. 1. Mitochondrial network in a mammalian fibroblast. A COS-7 cell labeled to visualize mitochondria (green) and microtubules (red) was analyzed by indirect immunofluorescence confocal microscopy. Mitochondria were labeled with antibodies to the β subunit of the F1-ATPase and a rhodamine-conjugated secondary antibody. Microtubules were labeled with antibody to tubulin and a fluorescein-conjugated secondary antibody. Pseudocolor was added to the digitized image. Scale: 1 cm = 10 μm.

INCOMING METABOLISED ENERGY

MAINTENANCE
(of existing cells)

+ 

GROWTH
(of new cells)
a) DOMINATED BY NON-LINEAR (UNIVERSAL) 1/4 - POWER SCALING

b) EXTRAORDINARY ECONOMIES OF SCALE (THE BIGGER YOU ARE, THE LESS YOU NEED PER “CAPITA”)

c) PACE OF LIFE SYSTEMATICALLY SLOWS WITH INCREASING SIZE;

d) GROWTH IS SIGMOIDAL REACHING A STABLE SIZE AT MATURITY

e) NETWORKS
SUSTAINABLE!!
ARE CITIES (AND COMPANIES) SCALED VERSIONS OF EACH OTHER?

DO THEY MANIFEST "UNIVERSALITY"?
Example of scaling relationships

a) Total WAGES per MSA in 2004 for the USA vs. metropolitan population.

b) SUPERCreative employment per MSA in 2003, for the USA vs. metropolitan population.

SUPER-LINEAR SCALING
Innovation measured by Patents
TOTAL CRIME (JAPAN)

Slope = 1.21 [1.08, 1.35]
UNIVERSALITY
DOUBLING THE SIZE OF A CITY
SYSTEMATICALLY INCREASES
INCOME, WEALTH, NUMBER OF PATENTS,
NUMBER OF COLLEGES, NUMBER OF
CREATIVE PEOPLE, NUMBER OF POLICE,
CRIME RATE, NUMBER OF AIDS & FLU CASES,
AMOUNT OF WASTE,...........

ALL BY APPROXIMATELY 15%
REGARDLESS OF CITY
NETWORK DYNAMICS DETERMINES THE PACE OF LIFE

IF THE SLOPE IS $< 1$  PACE OF LIFE SLOWS DOWN

IF THE SLOPE IS $> 1$  PACE OF LIFE SPEEDS UP
Pace of biological life vs. Pace of social life

Heart Rate vs. Body Size  Walking Speed vs. Population Size
FINANCIAL MARKETS, ECONOMIES, GLOBAL WARMING, ENVIRONMENT, URBANISATION, HEALTH, CRIME, POLLUTION, ………… ARE NOT INDEPENDENT THEY ARE ALL HIGHLY COUPLED, INTERRELATED COMPLEX ADAPTIVE SYSTEMS
Q: Some say that while the 20th century was the century of physics, we are now entering the century of biology. What do you think of this?
A: I think the next century will be the century of complexity.

Stephen Hawking interview, January, 2000
UNIVERSALITY OF SOCIAL NETWORKS
(CLUSTERING HIERARCHIES)
NEED A NEW PARADIGM, A NEW INTEGRATED CONCEPTUAL FRAMEWORK: SYSTEMIC, HOLISTIC, QUANTITATIVE, PREDICTIVE

“GRAND UNIFIED THEORY OF SUSTAINABILITY”
CITIES AND URBAN LIFE

a) SUPER-LINEAR DOMINATED BY INNOVATION & WEALTH CREATION

THE BIGGER YOU ARE, THE MORE YOU GET PER CAPITA OF EVERYTHING FROM INCOME AND INNOVATION TO CRIME, POLLUTION AND DISEASE - ALL TO THE SAME DEGREE (~15% FOR EVERY DOUBLING OF SIZE)

b) SYSTEMATIC INCREASE OF PACE OF LIFE

c) UNBOUNDED GROWTH vs COLLAPSE
Growth Equation

Total incoming rate (Resources, Products, Patents, …
… “Energy” or “Dollar” equivalent)

\[ \approx \text{Maintenance} \ (\text{Repair, Replacement, Sustenance,} \…\) + \text{Growth} \]
\( b < 1 \)  (SUB-LINEAR)  BOUNDED GROWTH
$b > 1$ (SUPER-LINEAR)

SUPER-EXPONENTIAL
UNBOUNDED GROWTH

COLLAPSE
UNBOUNDED GROWTH REQUIRES ACCELERATING CYCLES OF INNOVATION TO AVOID COLLAPSE
SUSTAINABLE????
Population growth for New York City
1790 - 2003
Successive cycles of superlinear innovation reset the singularity and postpones instability and subsequent collapse. The relative population growth rate of New York City over time reveals periods of accelerated (super-exponential) growth. Successive shorter periods of super exponential growth appear, separated by brief periods of deceleration. (Inset) $t_c$ for each of these periods vs. population at the onset of the cycle. Observations are well fit with $\beta = 1.09$ (green line).
UNBOUNDED GROWTH LEADING TO "FINITE-TIME SINGULARITY" & COLLAPSE

UNLESS INNOVATIONS (SYSTEMATICALLY) OCCUR FASTER AND FASTER

CONTINUOUS TENSION BETWEEN:

INNOVATION & WEALTH CREATION vs ECONOMIES OF SCALE
Average “idealised, universal” characteristics of cities of a given size (constrained by underlying principles and dynamics of network structures - manifested in scaling laws) vs.

Characteristics of specific cities as measured by deviations from scaling laws representing their individuality and local environment and conditions
Survival (S) vs. Age (Y) for the growth stages of a plant:

- Seed production
- Seed in soil
- Germinating seed
- Established seedling
- Early sapling
- Middle sapling
- Reproductive maturity
- Canopy

The equation for survival (S) over age (Y) is given by:

\[ \frac{1}{Y} = -0.006 + 0.036X \]
OUR “NATURAL” METABOLIC RATE  ~ 90 watts

OUR SOCIAL METABOLIC RATE  ~ 11,000 watts  !!!

WE ARE EQUIVALENT TO A  30,000 Kg GORILLA  !!!

REPRODUCTION RATE OF  ~ ONE OFFSPRING PER 15 years
Singularity is technological change so rapid and so profound that is represents a rupture in the fabric of human history.

Paradigm Shift Time (Years)

Body Plans (Cambrian Explosion: tens of millions)

Homo Sapiens (hundreds of thousands)

Stone Tools (tens of thousands)

Iron

Printing (century or two)

Phone

TV

Computers

Internet

Cell Phones

Paradigm Shift (Years ago)

Primitive Cells (billions)

Mammals

Primates

Humanoids (millions)

Singularity is technological change so rapid and so profound that is represents a rupture in the fabric of human history.
Singularity is near

The ever accelerating progress of technology...gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue.

John von Neumann (1903 - 1957)
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