NICHE CONSTRUCTION AND CUMULATIVE CULTURAL EVOLUTION

COMBINATORIAL INNOVATION AND ITS CONSEQUENCES, FROM PAST TO PRESENT

Roope Kaaronen
University of Helsinki

roopekaaronen.net

Old view: Humans are exceptional.

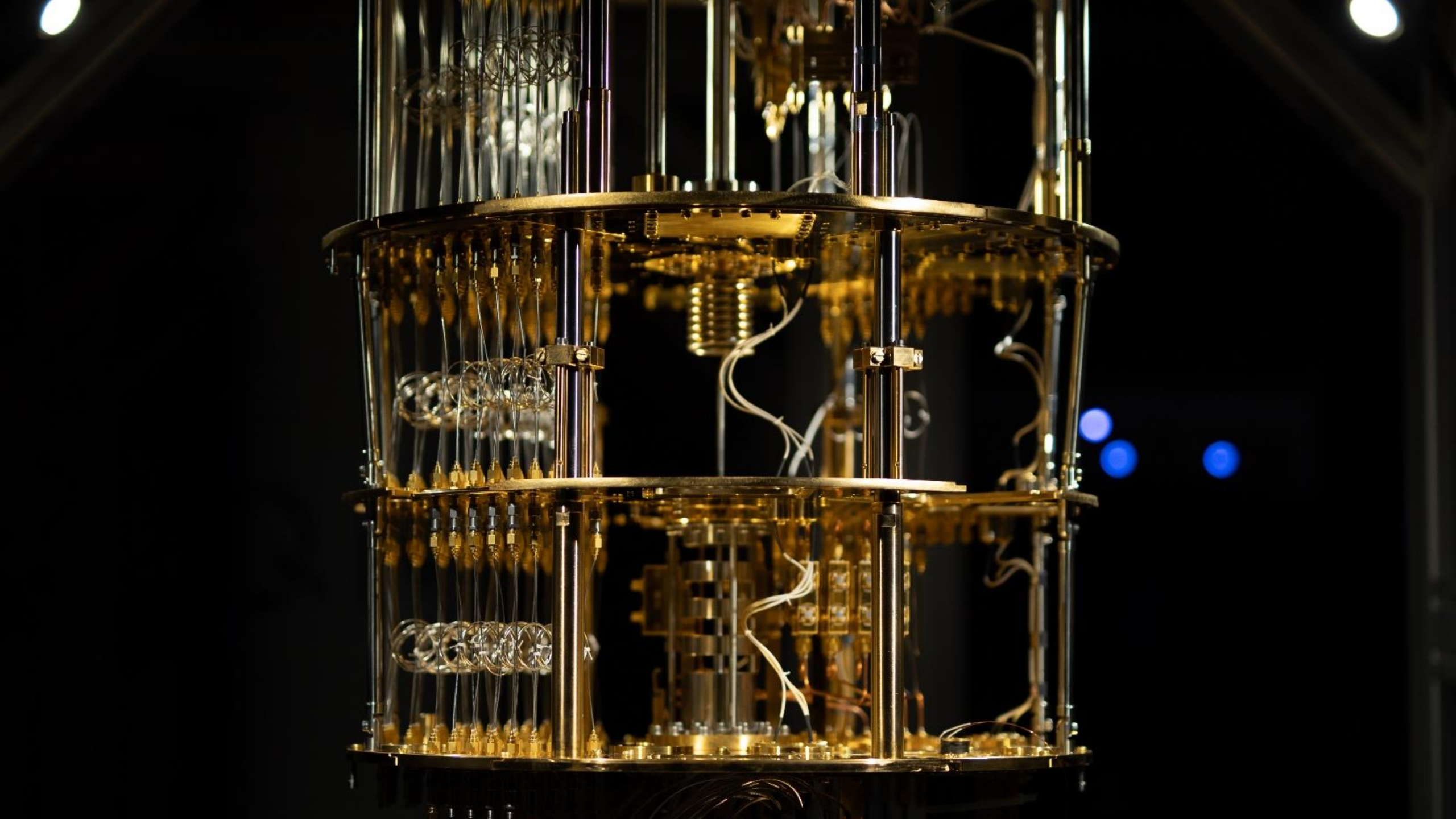
Modern view (genetics): “We're 96% the same as chimps.”

Yet... humans *are* different.

We are not behaviourally 96% similar.

We are certainly not technologically 96% similar.

Why?



Common answers:

Raw Intelligence – cognitive processing
Language – capacity for cultural transmission
Symbolic thought – capacity for representation
Ultrasociality – allows for cooperation, imitation
Tool use – extends our physical capacities
Foresight – planning ahead, mental ‘time travel’

“But...”

Cumulative Cultural Evolution

Knowledge and skills accumulate over generations

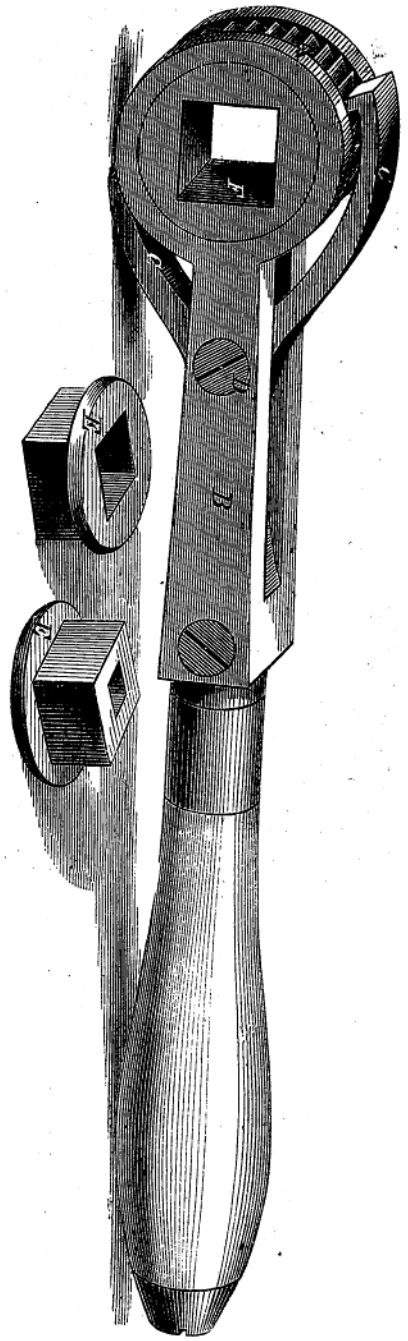
No reinventing the wheel — we inherit solutions

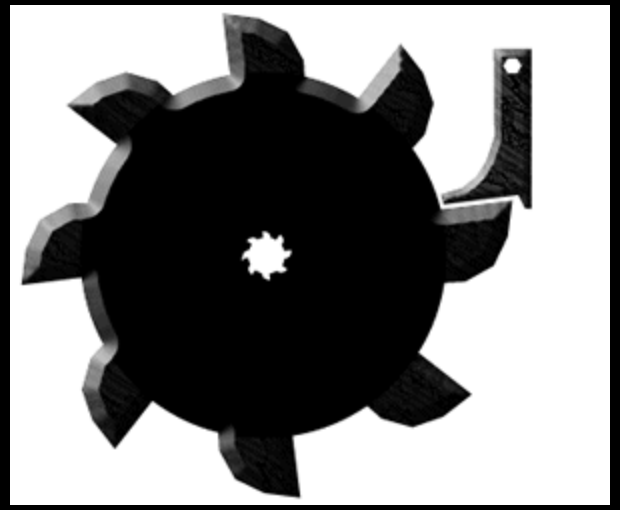
Precondition: Cultural transmission in *high-fidelity*

Ratchet effect: Cultural innovations are retained and refined, not lost

Gene-culture coevolution (selection for intelligence)

“Cultural inheritance” next to biological evolution





Cultural Niche Construction

We don't just adapt to environments, we change them

Feedback loops ("autocatalytic" processes): Our modifications accelerate further modifications.

Extends to the *social niche*: division of labour, alloparenting, etc.

Humans are the "ultimate" niche constructors (Lala: Darwin's Unfinished Symphony),

using products of behaviors to refine behaviors

The myth of the 'autodidact' – the border between individual and social learning is always fuzzy.

All Intelligence is Collective Intelligence

J. Benjamin Falandays[1*], Roope O. Kaaronen[2], Cody Moser[3], Wiktor Rorot[4], Joshua Tan[5], Vishwanath Varma[6], Tevin Williams[3], and Mason Youngblood[7]

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[2] Faculty of Biological and Environmental Sciences, University of Helsinki
[3] Department of Cognitive and Information Sciences, University of California, Merced
[4] Interdisciplinary Doctoral School, University of Warsaw
[5] Department of Computer Science, Oxford University
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Abstract

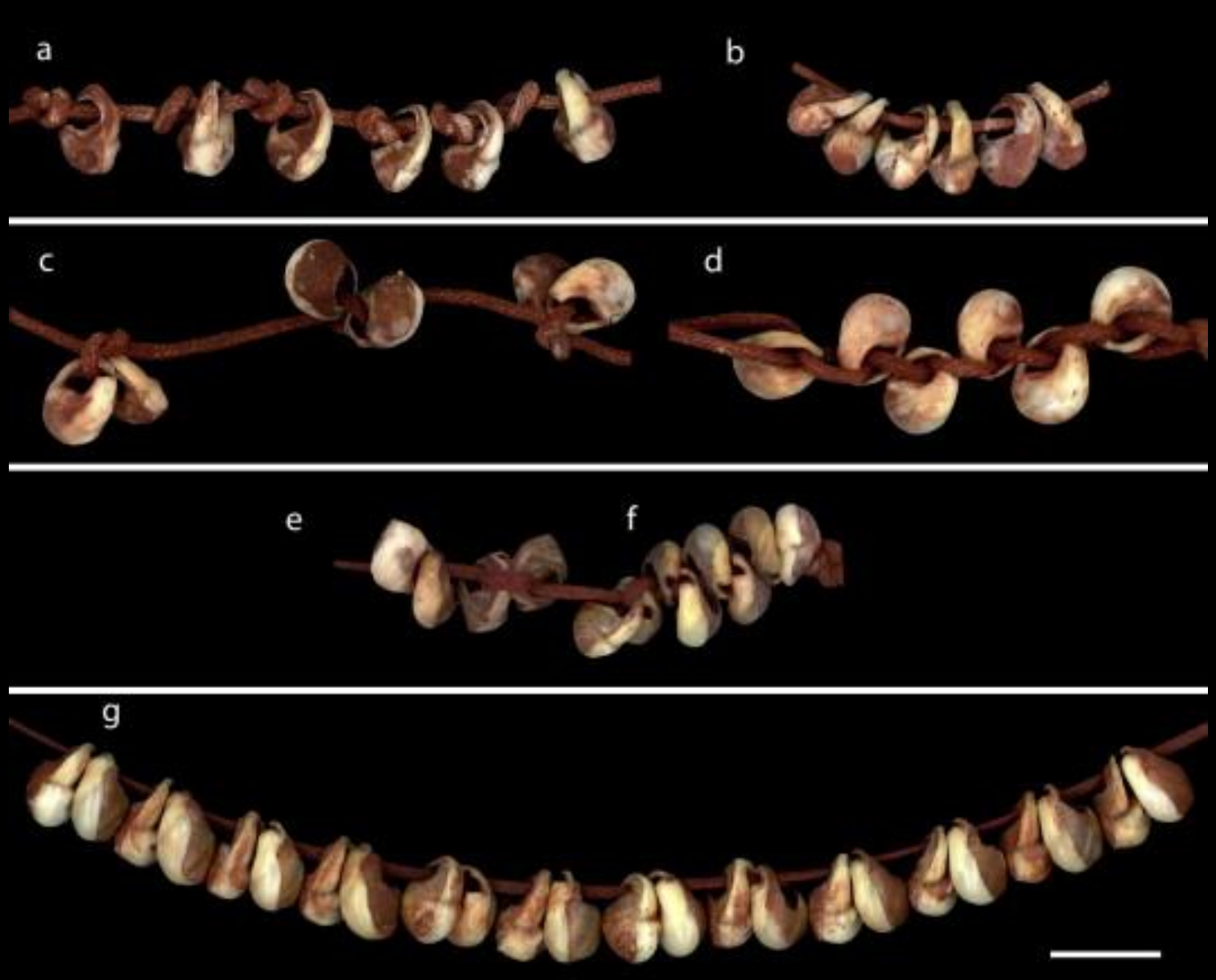
Collective intelligence, broadly conceived, refers to the adaptive behavior achieved by groups through the interactions of their members, often involving phenomena such as consensus building, cooperation, and competition. The standard view of collective intelligence is that it is a distinct phenomenon from supposed individual intelligence. In this position piece, we argue that a more parsimonious stance is to consider all intelligent adaptive behavior as being driven by similar abstract principles of collective dynamics. To illustrate this point, we highlight how similar principles are at work in the intelligent behavior of groups of non-human animals, multicellular organisms, brains, small groups of humans, cultures, and even evolution itself. If intelligent behavior in all of these systems is best understood as the emergent result of collective interactions, we ask what is left to be called "individual intelligence"? We believe that viewing all intelligence as collective intelligence offers greater explanatory power and generality, and may promote fruitful cross-disciplinary exchange in the study of intelligent adaptive behavior.

Is 'cumulative' enough?

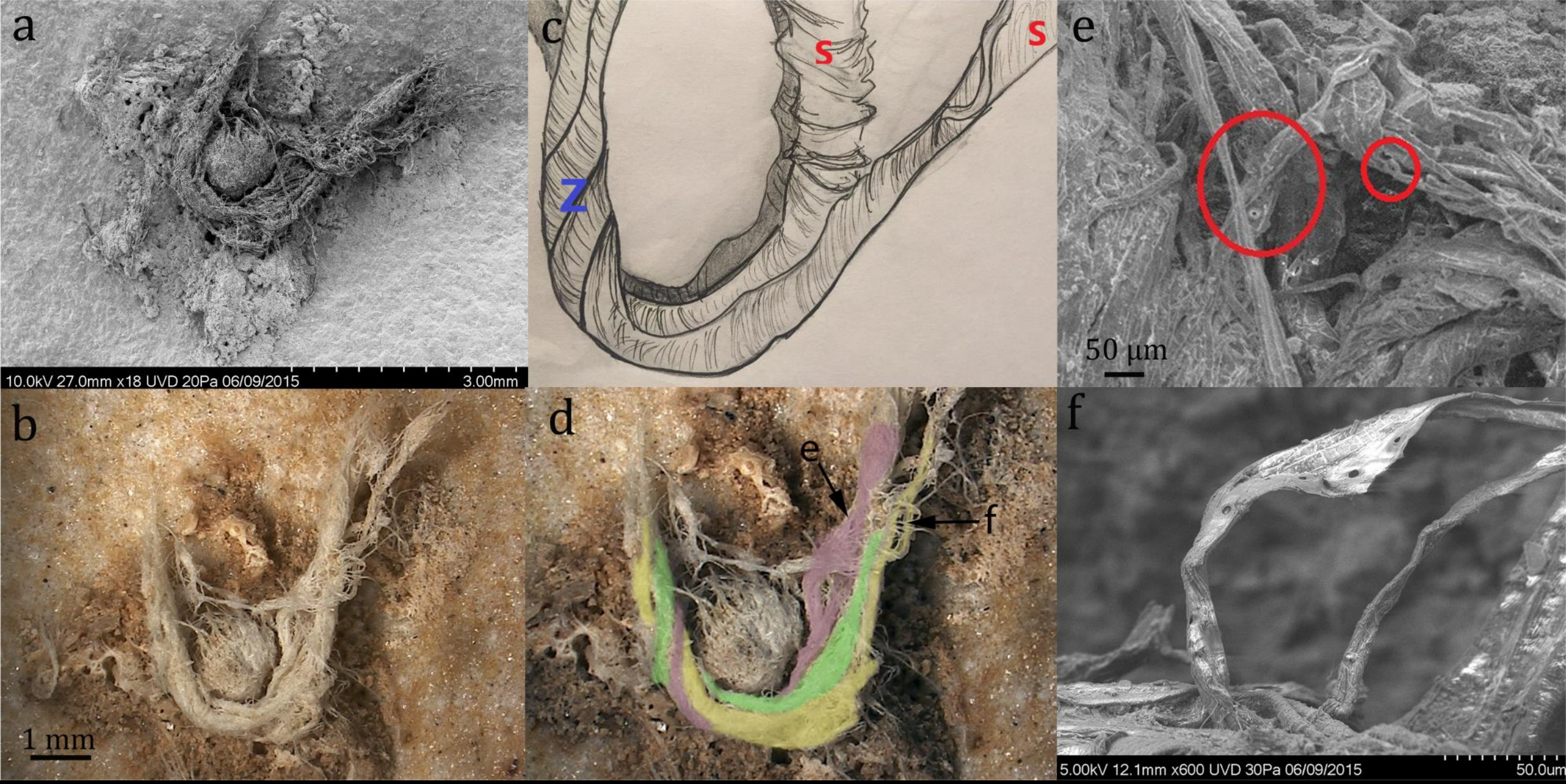
Is the 'ratchet' a good analogy?

Or is it something *more*?

Mayer, D. E. B.-Y., Groman-Yaroslavski, I., Bar-Yosef, O., Hershkovitz, I., Kampen-Hasday, A., Vandermeersch, B., Zaidner, Y., & Weinstein-Evron, M. (2020). On holes and strings: Earliest displays of human adornment in the Middle Palaeolithic. *PLOS ONE*, *15*(7), e0234924.

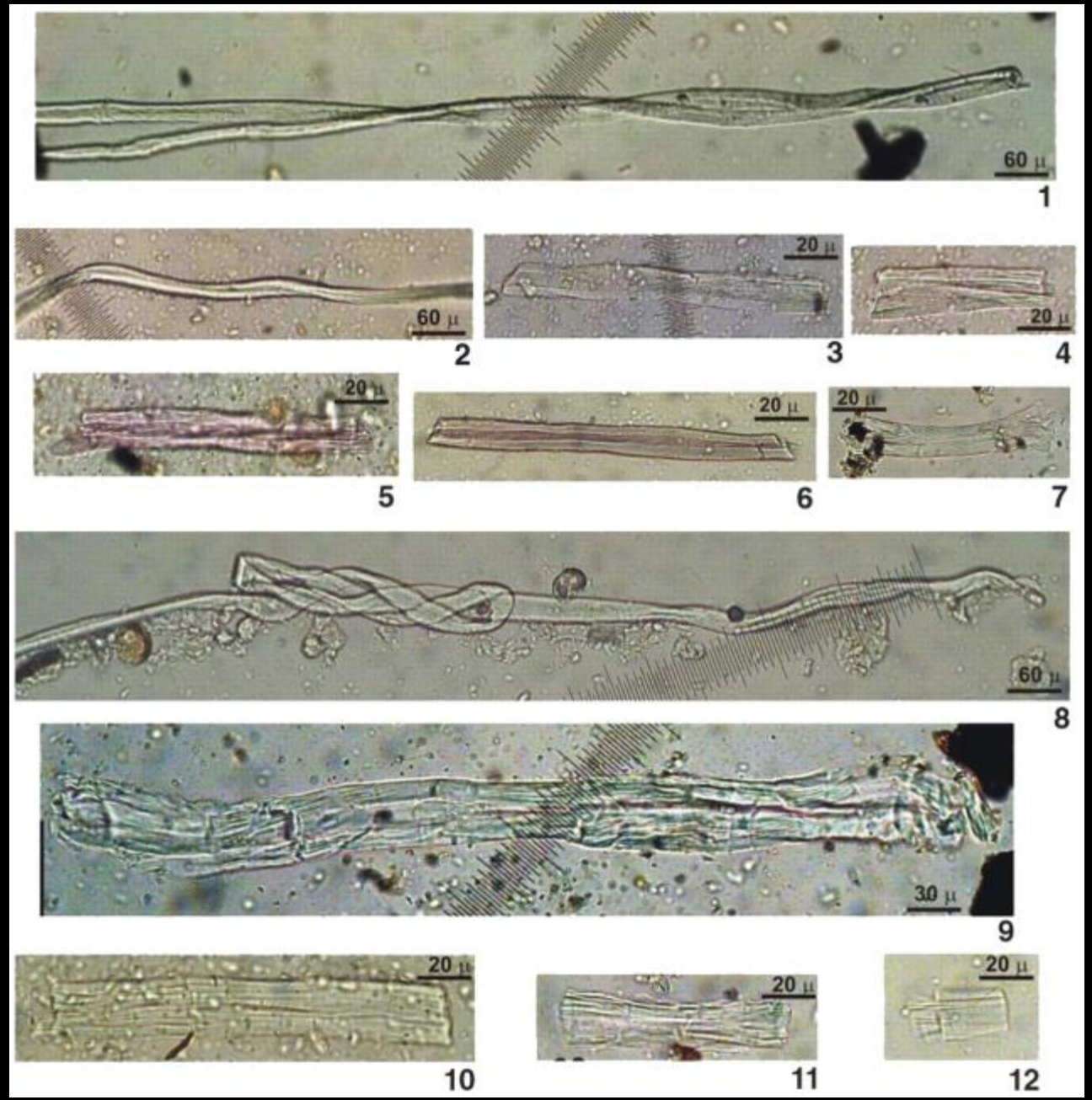


Vanhaeren, M., d'Errico, F., van Niekerk, K. L., Henshilwood, C. S., & Erasmus, R. M. (2013). Thinking strings: Additional evidence for personal ornament use in the Middle Stone Age at Blombos Cave, South Africa. *Journal of Human Evolution*, *64*(6), 500–517.

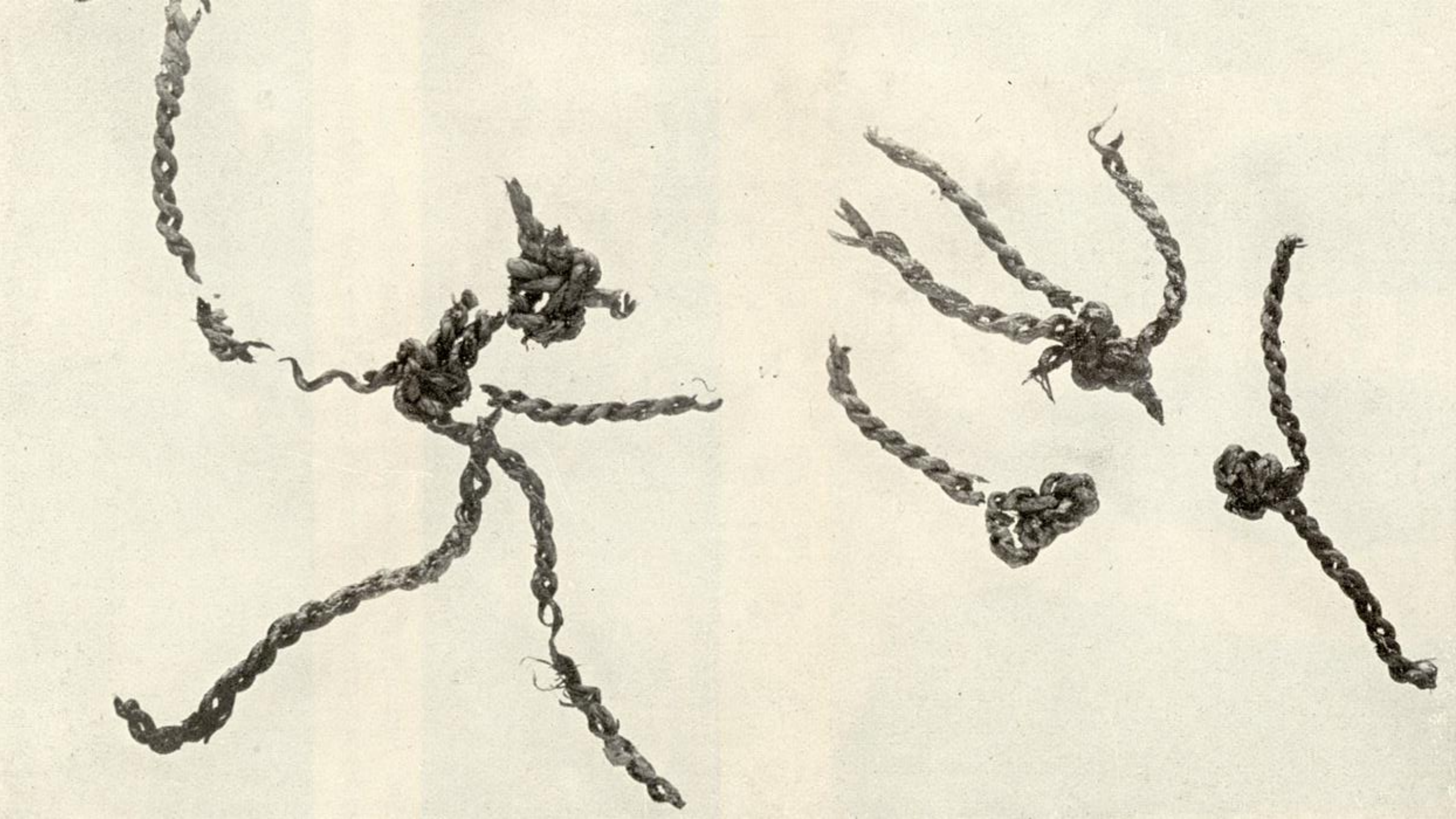


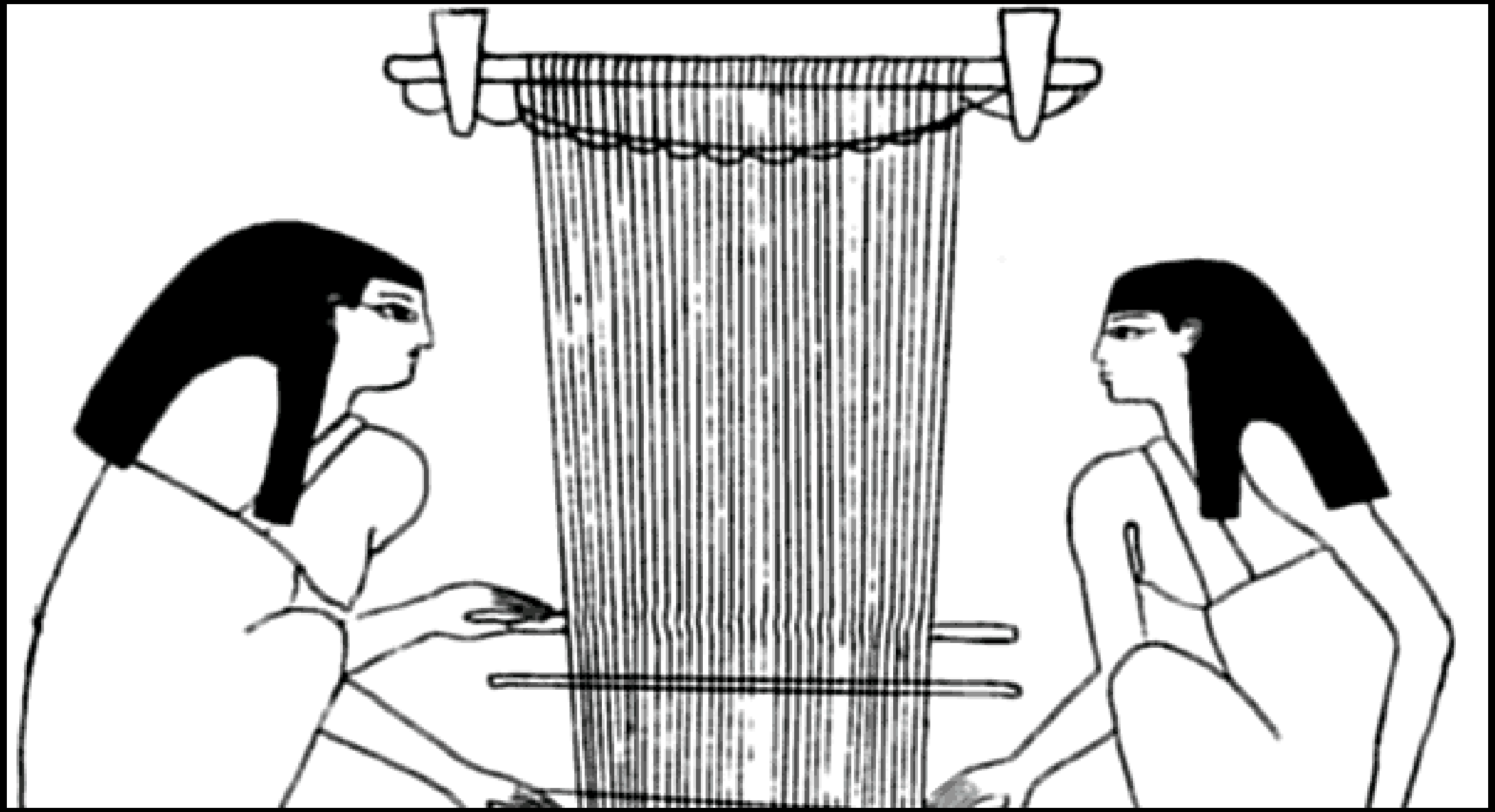
Hardy, B. L., Moncel, M.-H., Kerfant, C., Lebon, M., Bellot-Gurlet, L., & Mélard, N. (2020). Direct evidence of Neanderthal fibre technology and its cognitive and behavioral implications. *Scientific Reports*, *10*(1)

Conard, N. J., & Rots, V. (2024). Rope making in the Aurignacian of Central Europe more than 35,000 years ago. *Science Advances*, *10*(5), eadh5217.



Kvavadze, E., Bar-Yosef, O., Belfer-Cohen, A., Boaretto, E., Jakeli, N., Matskevich, Z., & Meshveliani, T. (2009). 30,000-Year-Old Wild Flax Fibers. *Science*, *325*(5946), 1359–1359.





Tomb of Khnumhotep II (ca. 4 kya)

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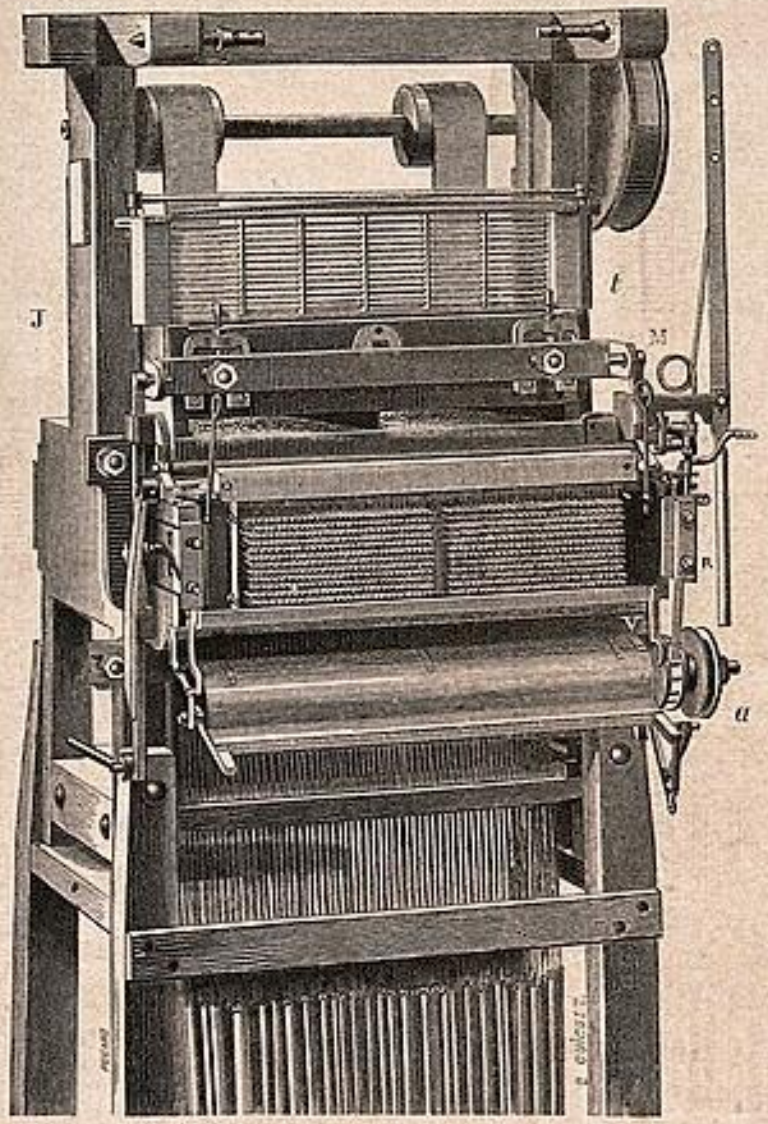

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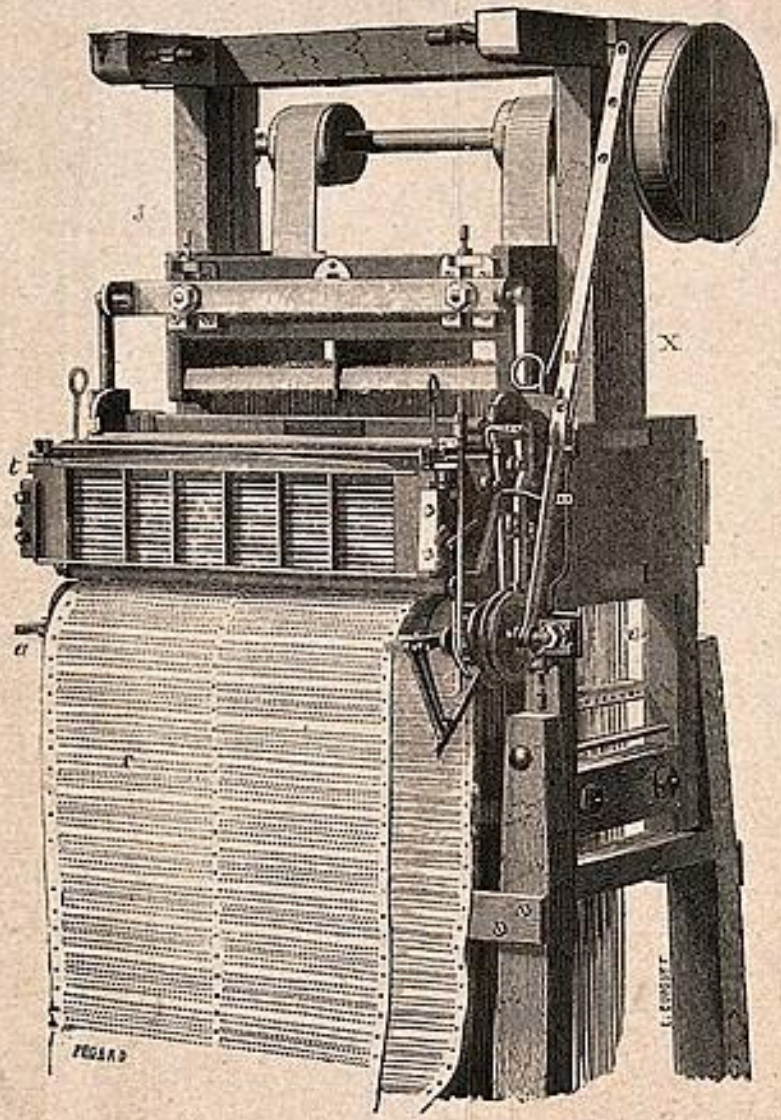
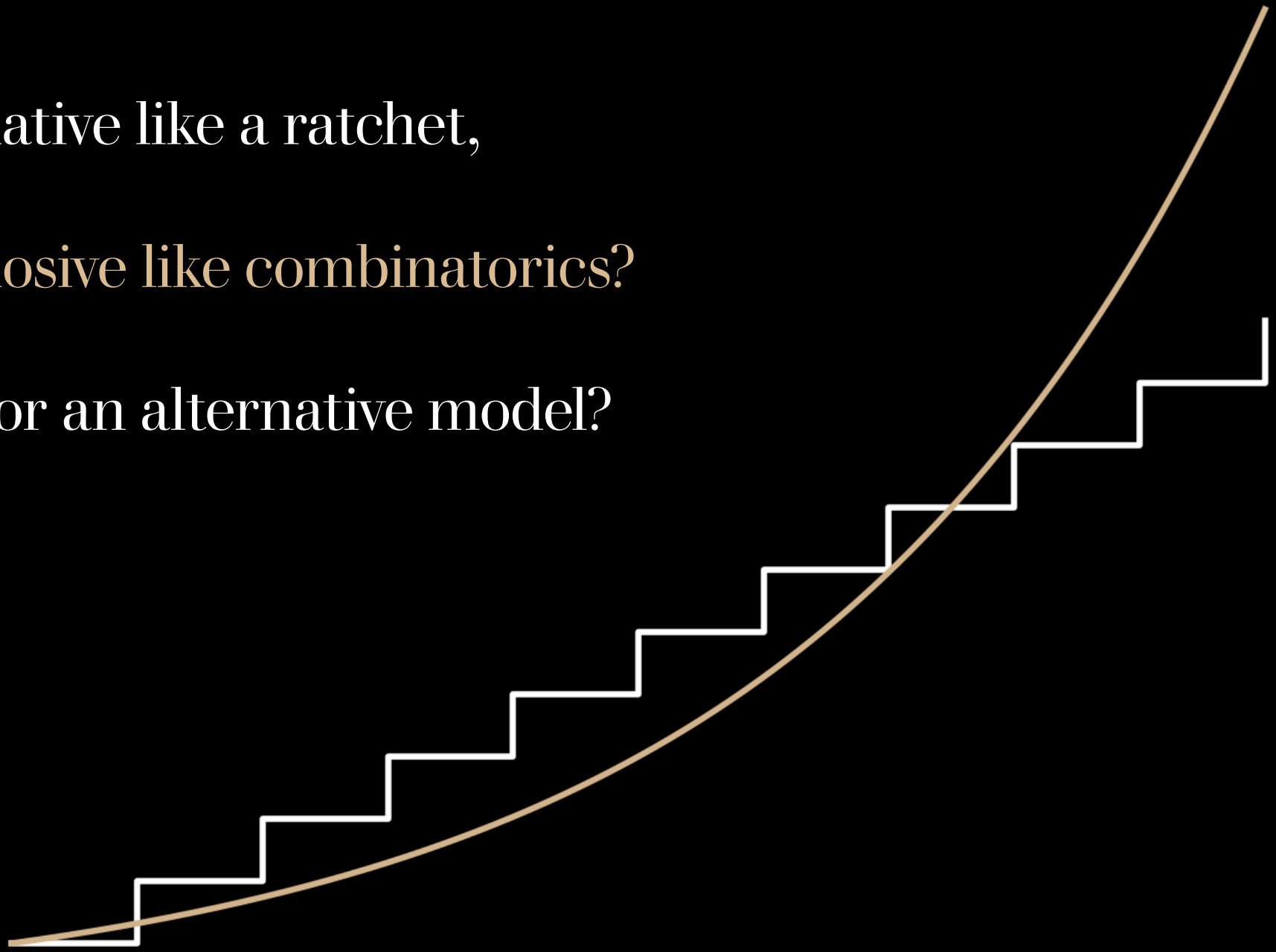
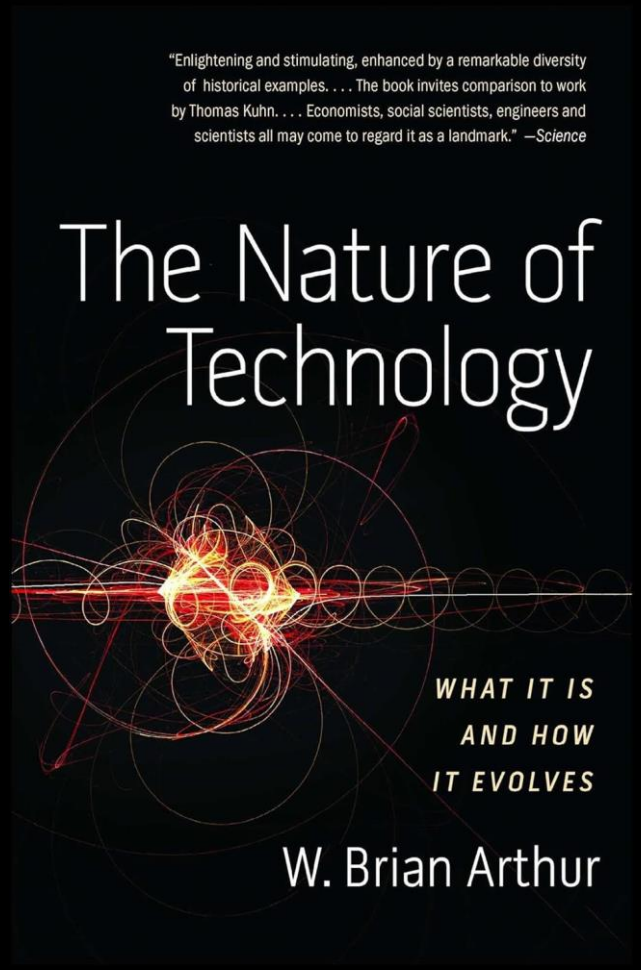


Cumulative like a ratchet,

or explosive like combinatorics?

Need for an alternative model?





Combinatorial Cultural Evolution

Culture, technology are largely combinatory

Recombining things and *ideas*

Information theory was a recombination of...

Boolean Logic (algebra of logic)

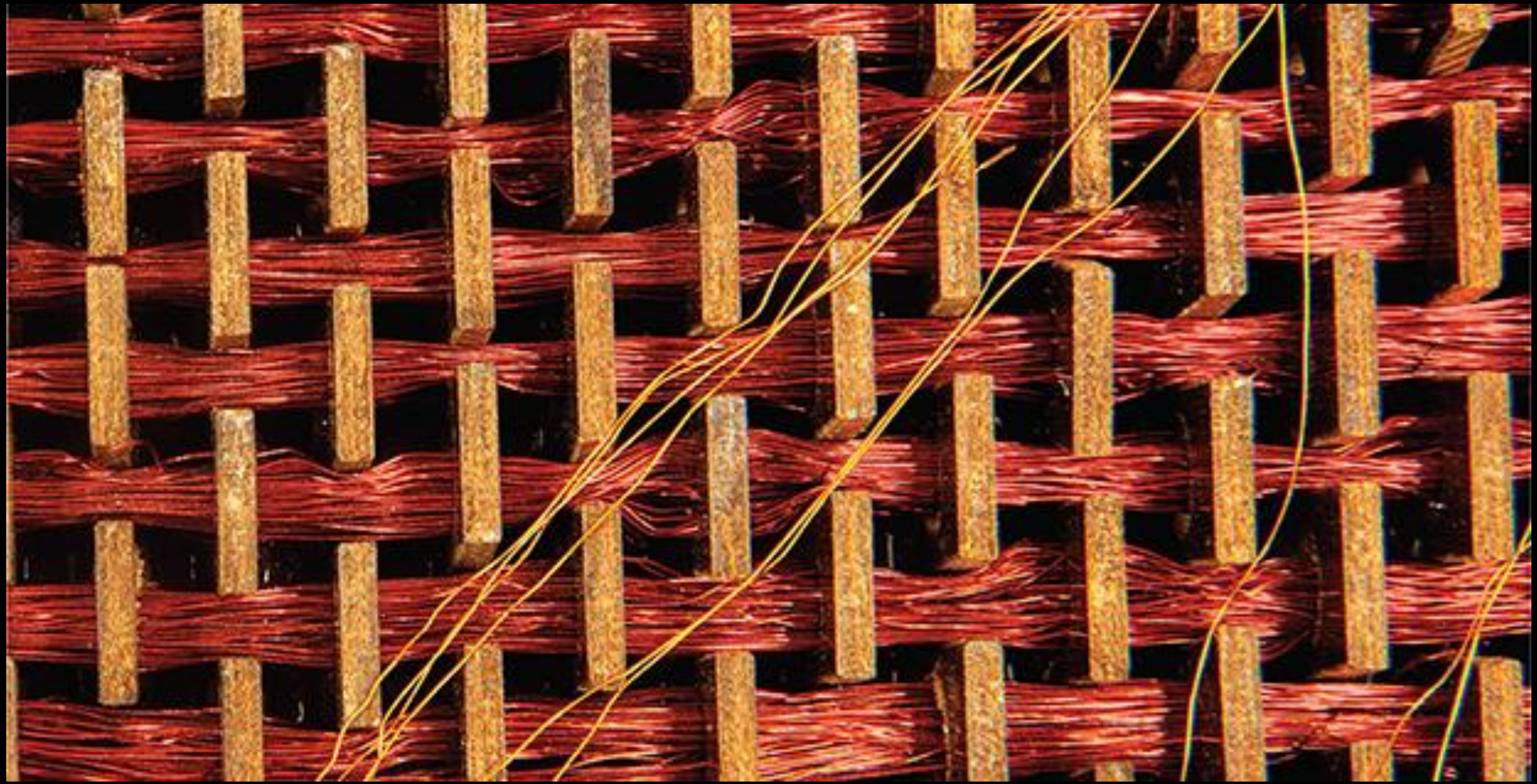
Electrical Circuits

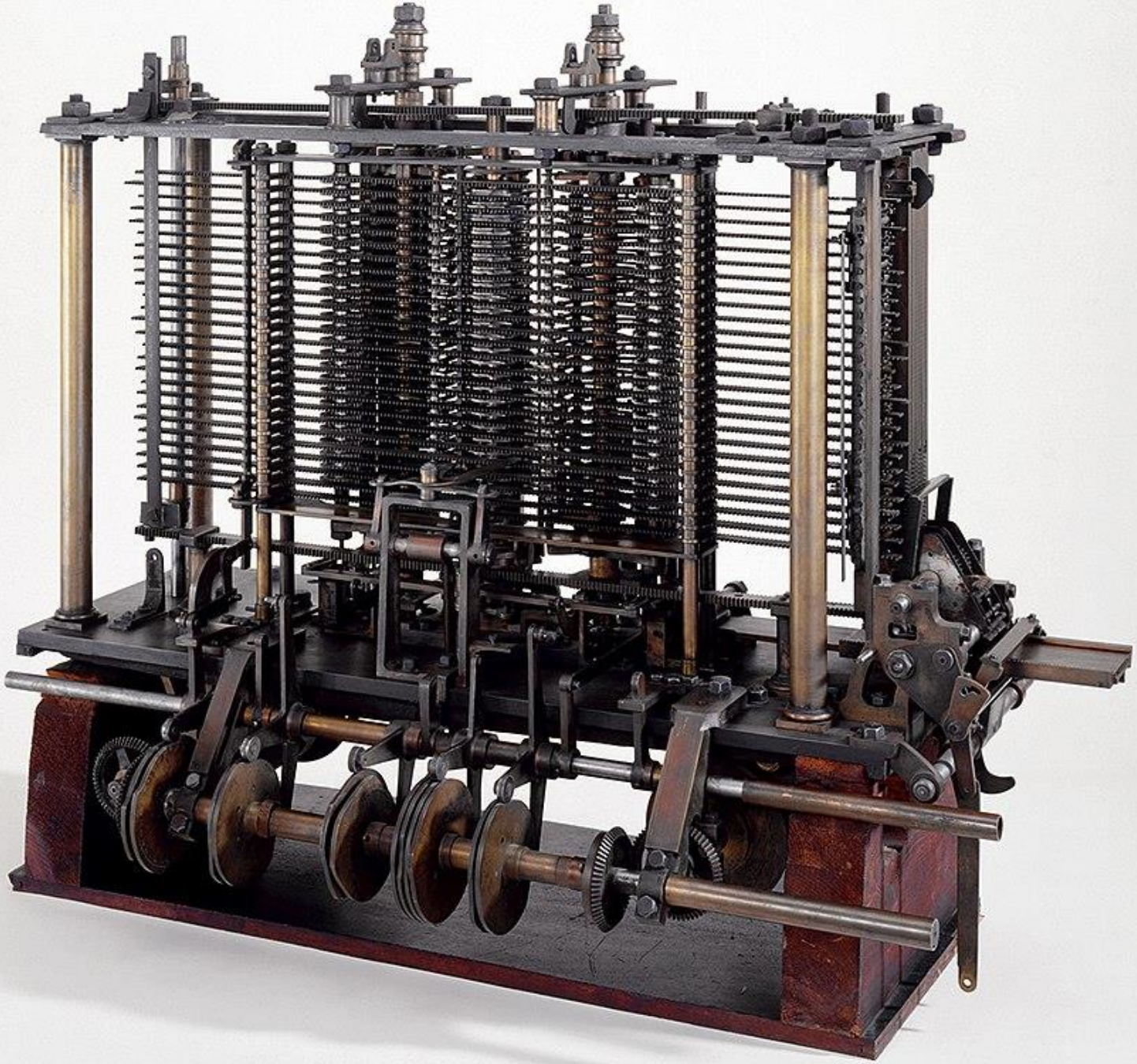
Probability Theory

Telecommunications Engineering (telegraphs, telephones, radio, cables)

Statistical Mechanics (physics, entropy)

...which then enabled digital communication, cryptogtaphy, bioinformatics...



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Cambridge Archaeological Journal (2025), 1–17
doi:10.1017/S0959774325000071

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Research Article

The Ties That Bind: Computational, Cross-cultural Analyses of Knots Reveal Their Cultural Evolutionary History and Significance

Roope O. Kaaronen[1], Allison K. Henrich[2], Mikael A. Manninen[1], Matthew J. Walsh[3], Isobel Wisher[4], Jussi T. Eronen[1,5] & Felix Riede[4]

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Abstract

Integral to the fabric of human technology, knots have shaped survival strategies since their first invention. As the ties that bind, their evolution and diversity have afforded human cultural change and expression. This study examines knotting traditions over time and space. We analyse a sample of 338 knots from 86 ethnographically or archaeologically documented societies over 12 millennia. Utilizing a novel approach that combines knot theory with computational string matching, we show that knotted structures can be precisely represented and compared across cultures. This methodology reveals a staple set of knots that occur cross-culturally, and our analysis offers insights into their cultural transmission and the reasons behind their ubiquity. We discuss knots in the context of cultural evolution, illustrating how the ethnographic and archaeological records suggest considerable know-how in knot-tying across societies spanning from the deep past to contemporary times. The study also highlights the potential of this methodology to extend beyond knots, proposing its applicability to a broader range of string and fibre technologies.

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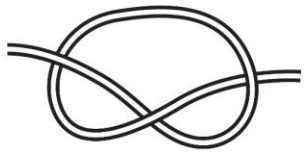

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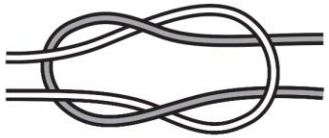

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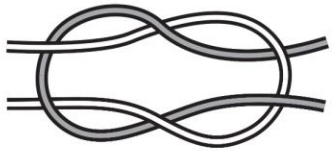

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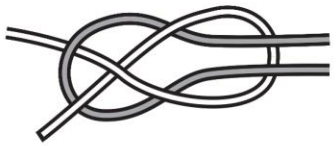

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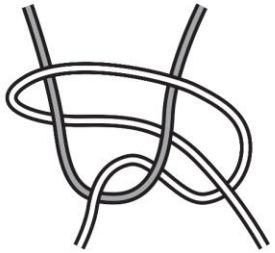

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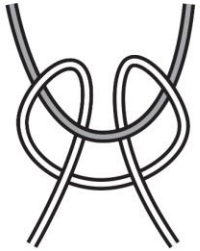

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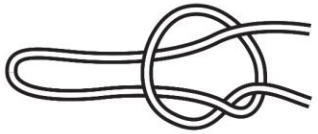

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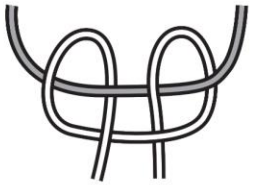

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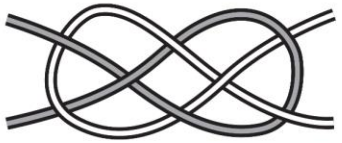

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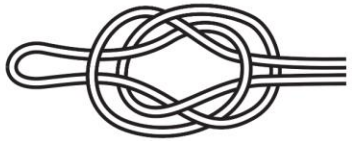

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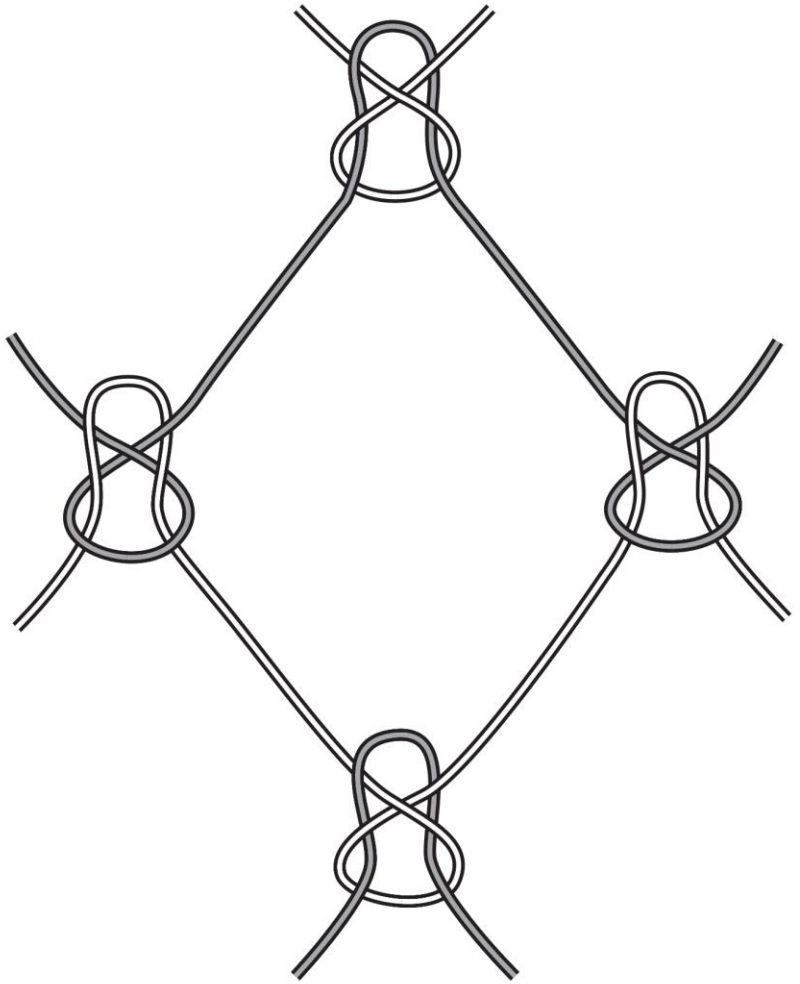

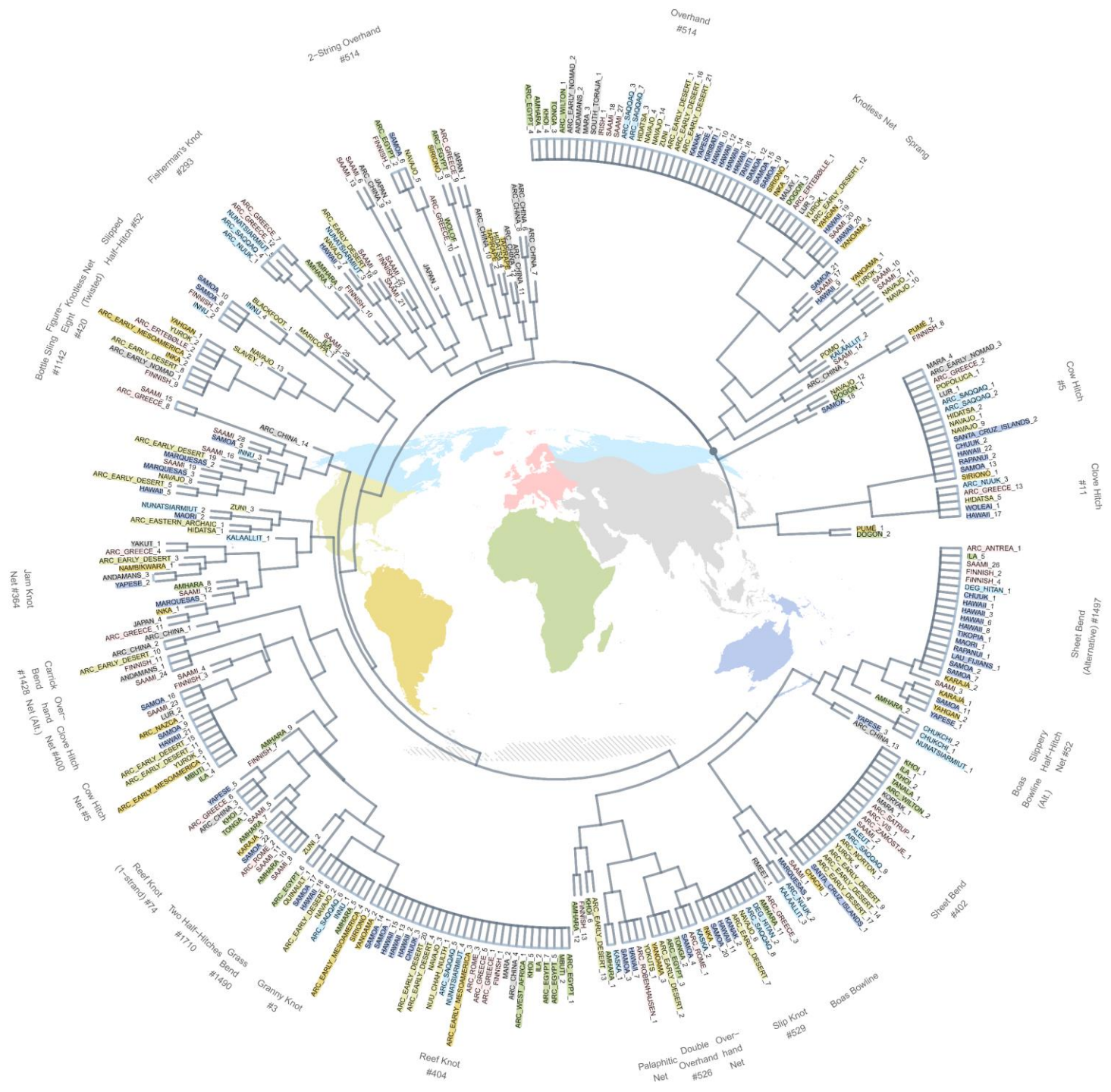
Overhand #514
2-String Overhand #514
Knotless Net
Sprang
Fisherman's Knot #293
Slipped Half-Hitch #52
Figure-Eight Knotless Net (Twisted) #420
Bottle Sling #1142
Cow Hitch #5
Clove Hitch #11
Sheet Bend (Alternative) #1497
Jam Knot Net #364
Carrick Bend #1428
Net (Alt.)
Over-hand Net #400
Clove Hitch
Cow Hitch Net #5
Slippery Half-Hitch Net #52
Boas Bowline (Alt.)
Sheet Bend #402
Reef Knot (1-strand) #74
Two Half-Hitches #1710
Grass Bend #1490
Granny Knot #3
Reef Knot #404
Palaphitic Net
Double Overhand #526
Over-hand Net
Slip Knot #529
Boas Bowline

Is the cultural evolution of technology cumulative or combinatorial?

James Winters*[1,2]

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[2]Mint Group, Max Planck Institute for the Science of Human History, Germany

September 25, 2020

Abstract

Explanations of human technology often point to both its *cumulative* and *combinatorial* character. Using a novel computational framework, where individual agents attempt to solve problems by modifying, combining and transmitting technologies in an open-ended search space, this paper re-evaluates two prominent explanations for the cultural evolution of technology: that humans are equipped with (i) social learning mechanisms for *minimizing information loss* during transmission, and (ii) creative mechanisms for generating novel technologies via *combinatorial innovation*. Here, both information loss and combinatorial innovation are introduced as parameters in the model, and then manipulated to approximate situations where technological evolution is either more cumulative or combinatorial. Compared to existing models, which tend to marginalize the role of purposeful problem-solving, this approach allows for indefinite growth in complexity while directly simulating constraints from history and computation. The findings show that minimizing information loss is only required when the dynamics are strongly cumulative and characterised by incremental innovation. Contrary to previous findings, when agents are equipped with a capacity for combinatorial innovation, low levels of information loss are neither necessary nor sufficient for populations to solve increasingly complex problems. Instead, higher levels of information loss are advantageous for unmasking the potential for combinatorial innovation. This points to a parsimonious explanation for the cultural evolution of technology without invoking separate mechanisms of stability and creativity.

How important is *high-fidelity* in cultural transmission?

Often, innovations deviate from 'intended' use.

$$M_{t+1} = M_t + P\sum_{i=1}^{M_t} \alpha_i \binom{M_t}{i}$$

Cazzolla Gatti, R., Koppl, R., Fath, B. D., Kauffman, S., Hordijk, W., & Ulanowicz, R. E. (2020). On the emergence of ecological and economic niches. *Journal of Bioeconomics*, *22*, 99–127.

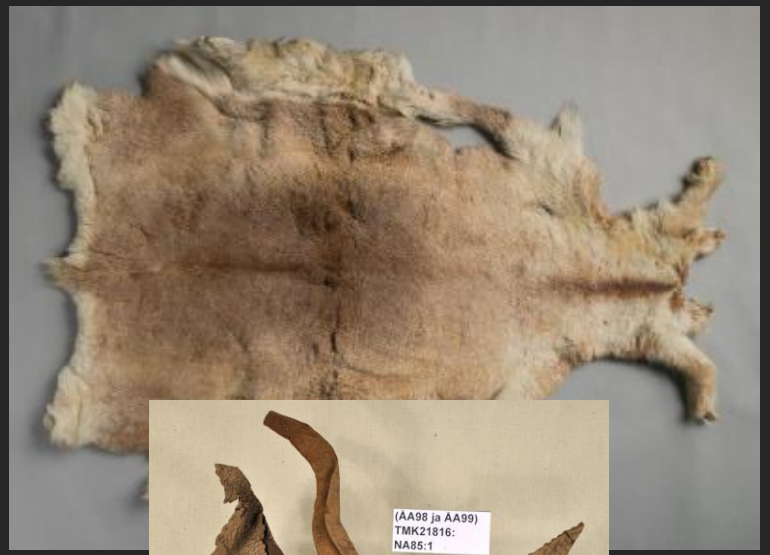
Theory of Adjacent Possible

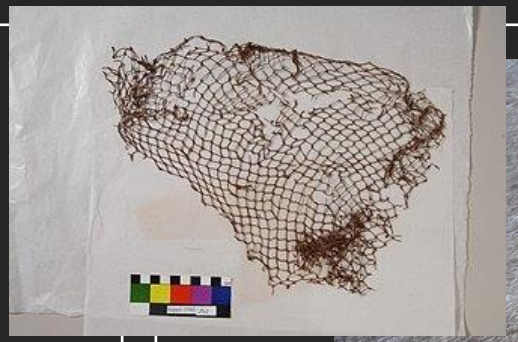
Stuart Kauffman

The horizon of possible things, given current affordances (*exaptations*)

Adjacent Possible ~ Combinations of existing parts

Tomorrow's technological landscape is a (weighted) recombination of today's technologies.



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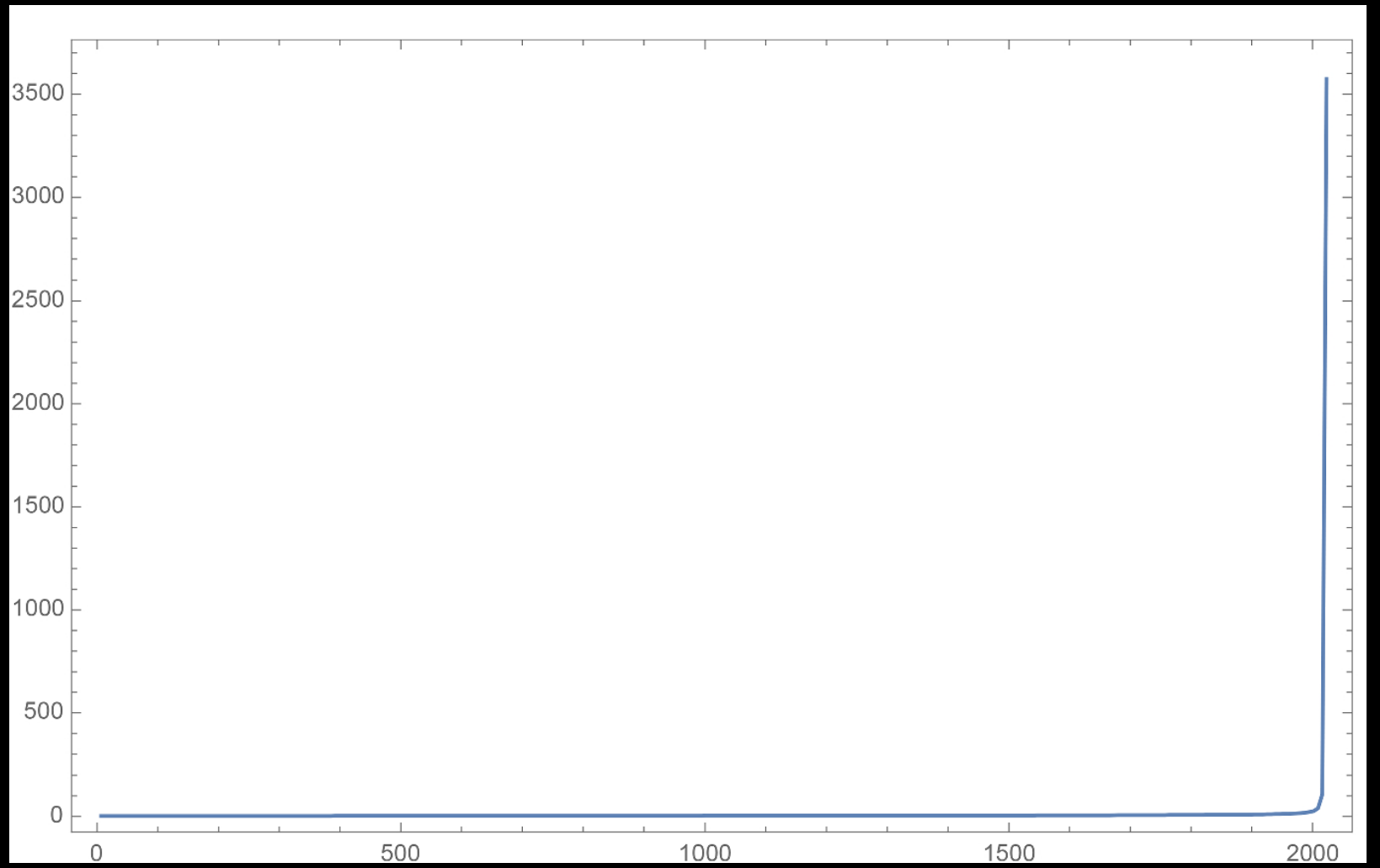
HOW CAN LESS BE MORE

MORE IS MORE



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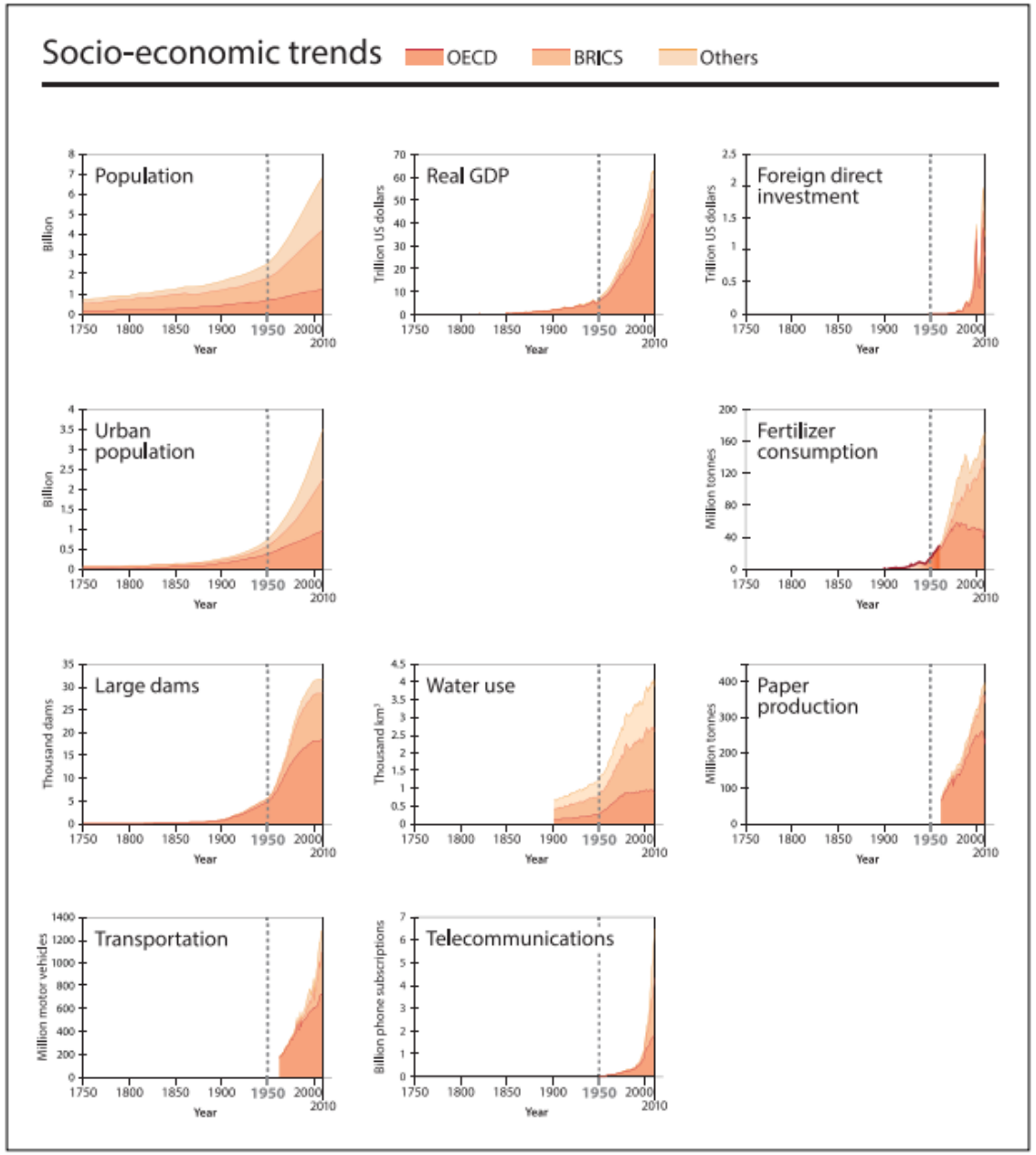


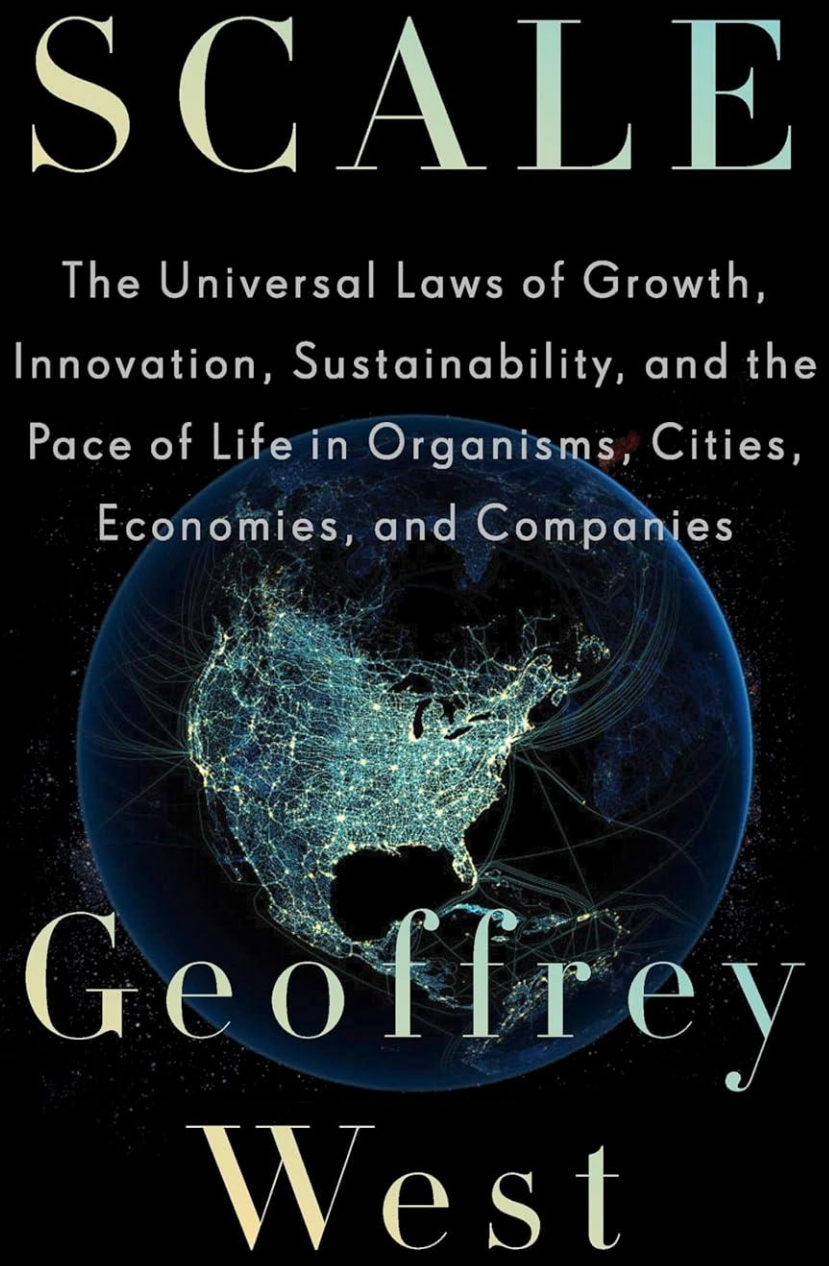
Figure 2. Trends from 1750 to 2010 for ten of the socio-economic graphs (excluding primary energy use and international tourism) with three splits for: the OECD countries, the so-called BRICS (Brazil, Russia, India, China (including Macau, Hong Kong and Taiwan where applicable), and South Africa) countries, and the rest of the world.

Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., & Ludwig, C. (2015). The trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review*, *2*(1), 81–98.

Culture is not just cumulative,
it is combinatorial.

Where does recombination happen?


MetLife



The Combinatorial City

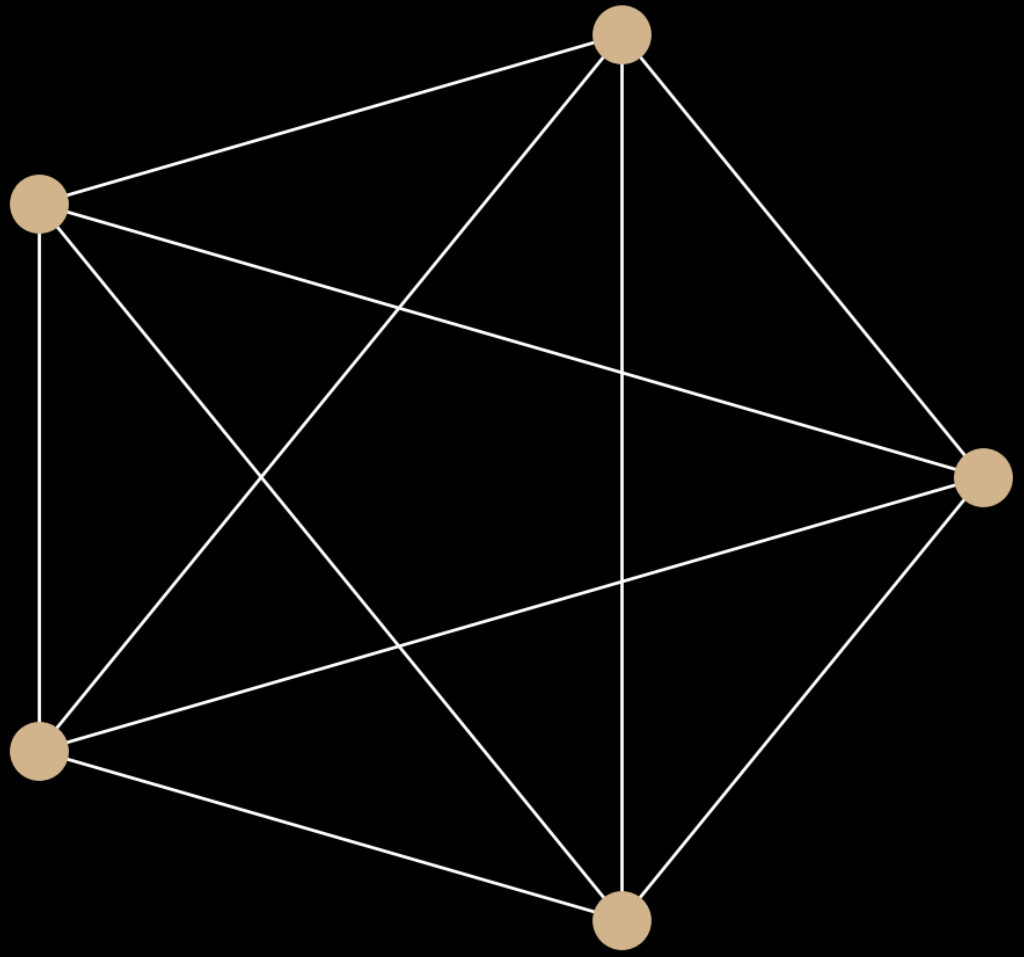
Jane Jacobs, Geoffrey West

Physical and social proximity fuels innovation through recombination (social networks)

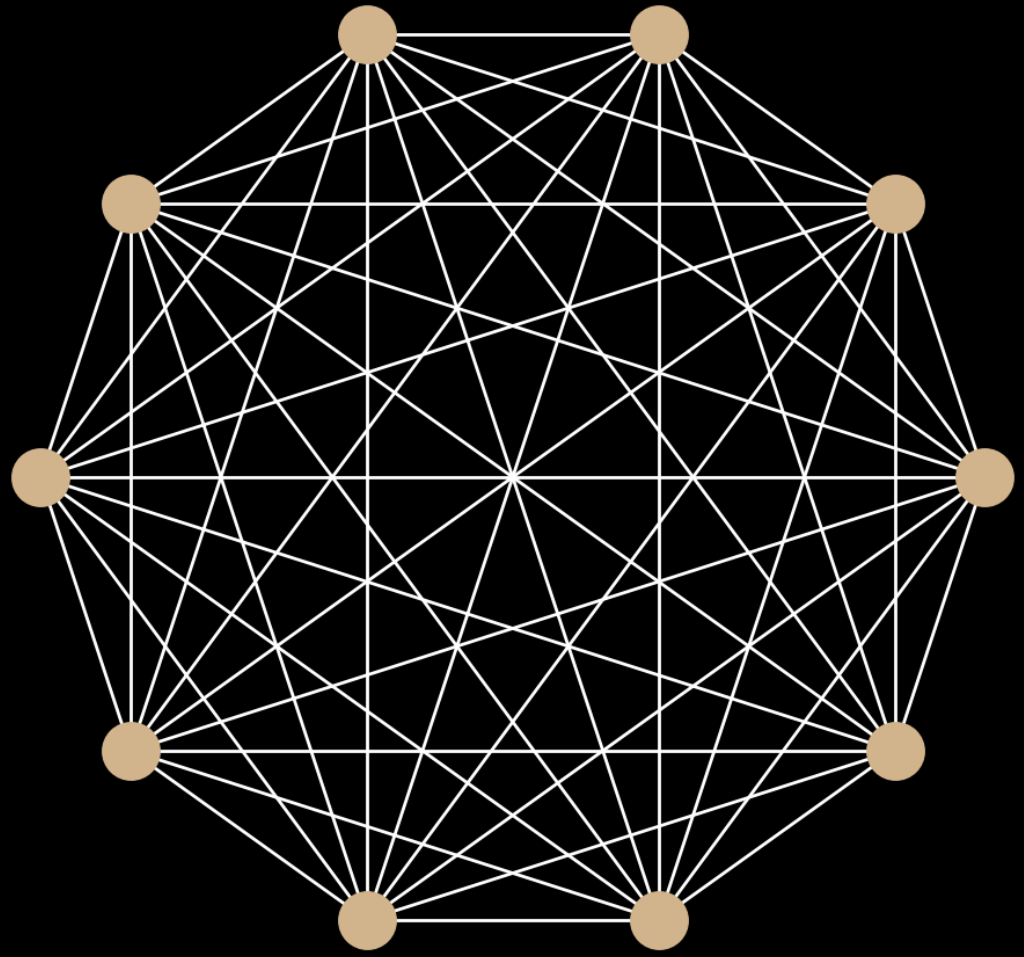
Superlinear scaling: Double the size of a city, you *more than* double innovation, productivity, etc.

Cities grow, the Adjacent Possible expands.

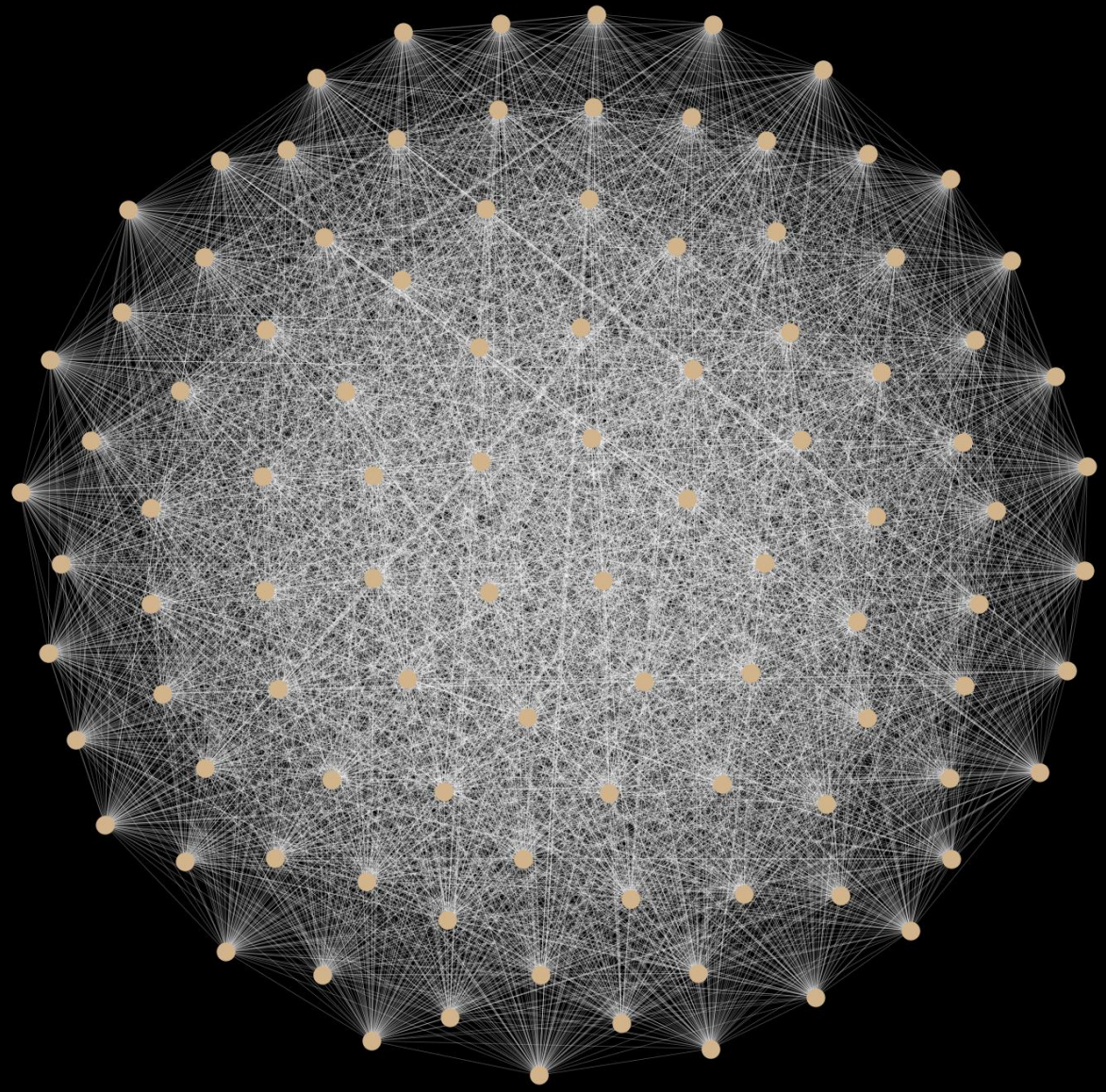
5 People = 10 Connections



10 People = 45 Connections



100 People = 4,950 Connections




INTERNET ARCHIVE

HobbyHall.fi

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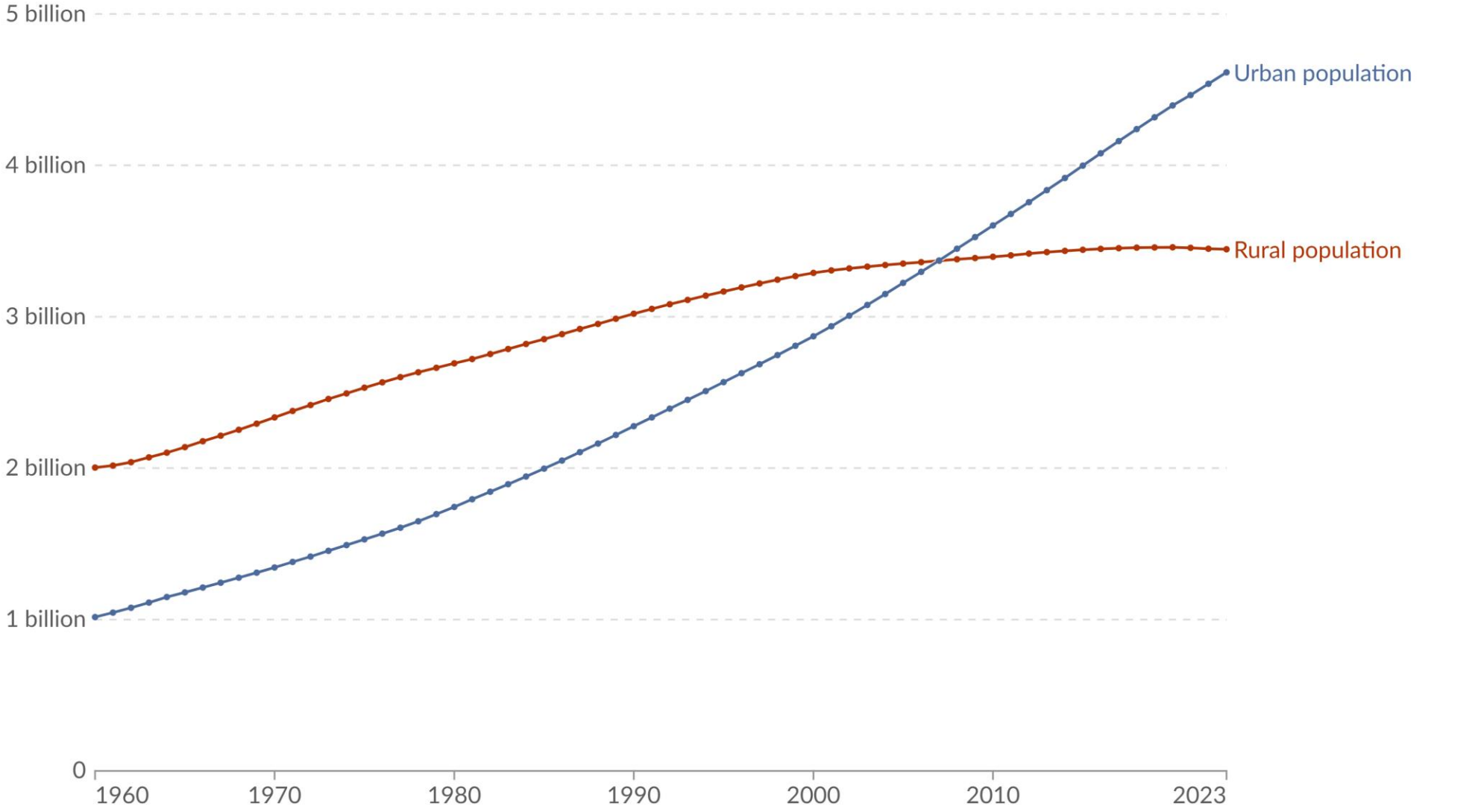
Number of people living in urban and rural areas, World

Our World in Data



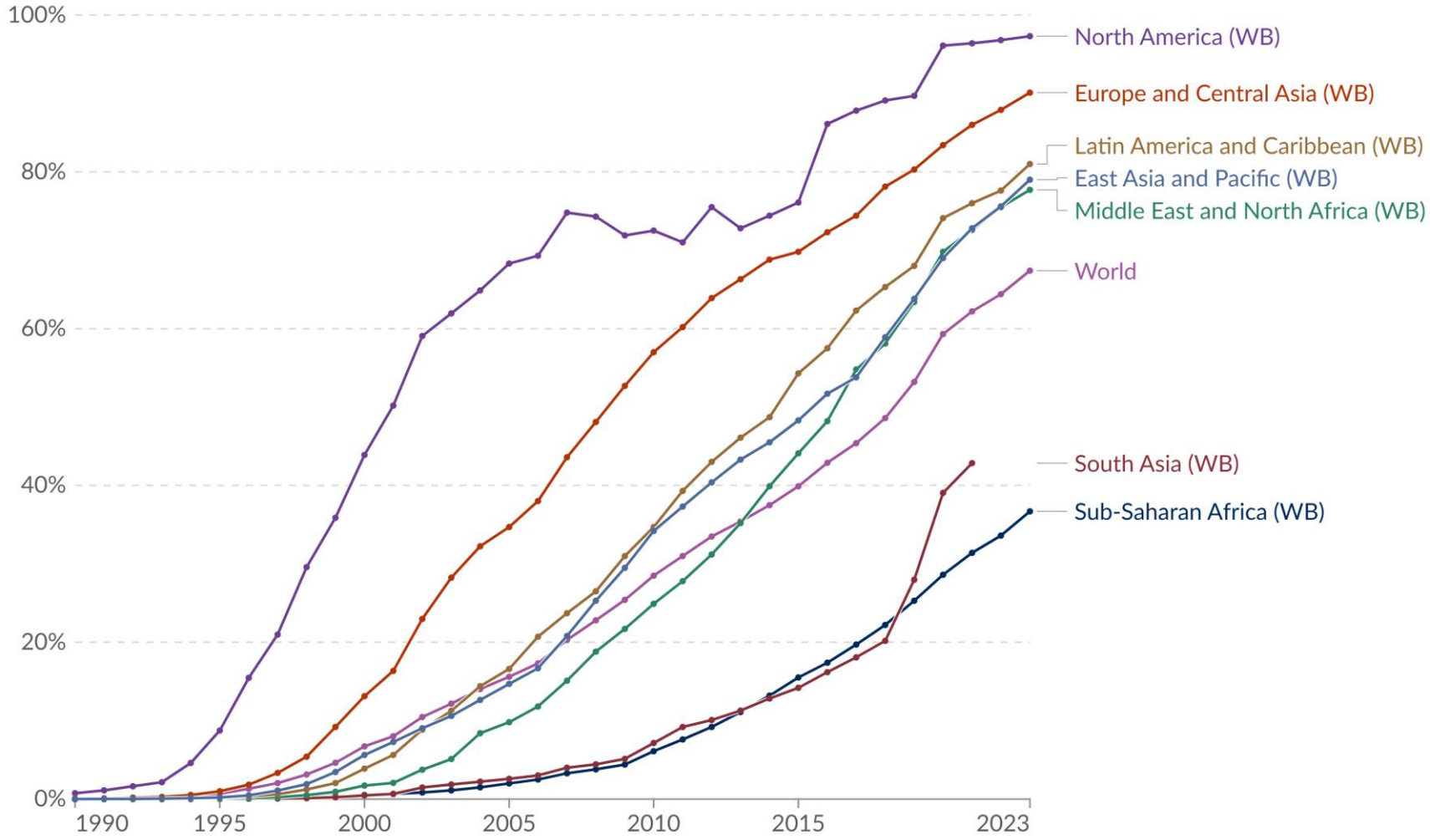
Data source: World Bank based on data from the UN Population Division (2025)

OurWorldinData.org/urbanization | CC BY

Note: Because the estimates of city and metropolitan areas are based on national definitions of what constitutes a city or metropolitan area, cross-country comparisons should be made with caution.

Share of the population using the Internet

Share of the population who used the Internet[1] in the last three months.



Data source: International Telecommunication Union (via World Bank) (2025)

OurWorldinData.org/internet | CC BY

1. Internet user: An internet user is defined by the International Telecommunication Union as anyone who has accessed the internet from any location in the last three months. This can be from any type of device, including a computer, mobile phone, personal digital assistant, games machine, digital TV, and other technological devices.

Decoupling for ecological sustainability: A categorisation and review of research literature

T. Vadén [a], V. Lähde [a], A. Majava [a], P. Järvensivu [a b], T. Toivanen [a c], E. Hakala [a d], J.T. Eronen [a e]

Highlights

- We reviewed 179 articles on decoupling published between 1990–2019.
- The papers present evidence of absolute impact decoupling, mainly between CO2 and GDP.
- No evidence of economy-wide, national/international absolute resource decoupling.
- No evidence of the kind of decoupling needed for ecological sustainability.
- In the absence of robust evidence, the goal of decoupling rests partly on faith.

Tipping the urban niche?

Autocatalysis: Not just runaway growth — but runaway solutions?

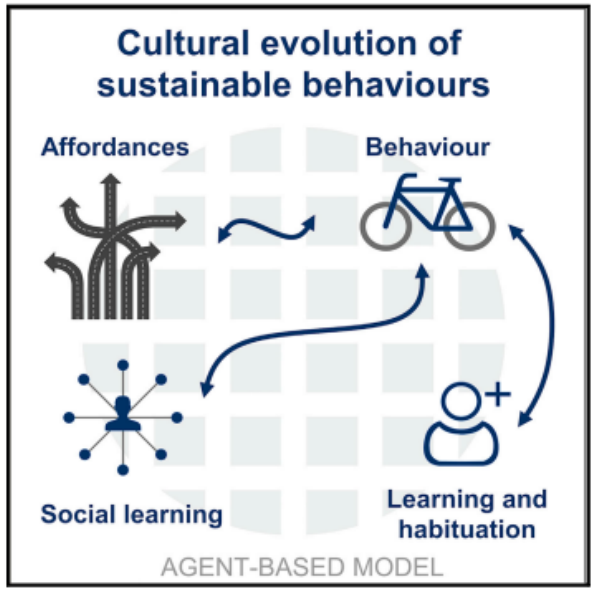
Niche construction for the Anthropocene.

Article

One Earth

Cultural Evolution of Sustainable Behaviors: Pro-environmental Tipping Points in an Agent-Based Model

Graphical Abstract



Highlights

- An ABM is used to study the cultural evolution of sustainable behaviors
- Behaviors emerge as a function of affordances, social learning, and habits
- The affordances in an environment have a major effect on behavior adoption
- The ABM is validated against cycling behaviors in Copenhagen

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In Brief

Kaaronen and Strelkovskii have designed an agent-based model to study the cultural evolution of sustainable behaviors. Behaviors emerge as a product of personal, environmental, and social factors. Particularly the structure of the environment has an effect on the adoption of pro-environmental behaviors. Even linear changes in pro-environmental affordances (action opportunities) can trigger non-linear collective behavior change. The model is validated against cycling behaviors in Copenhagen. This model gives further justification for policies and urban design that make pro-environmental behavior psychologically salient, accessible, and easy.

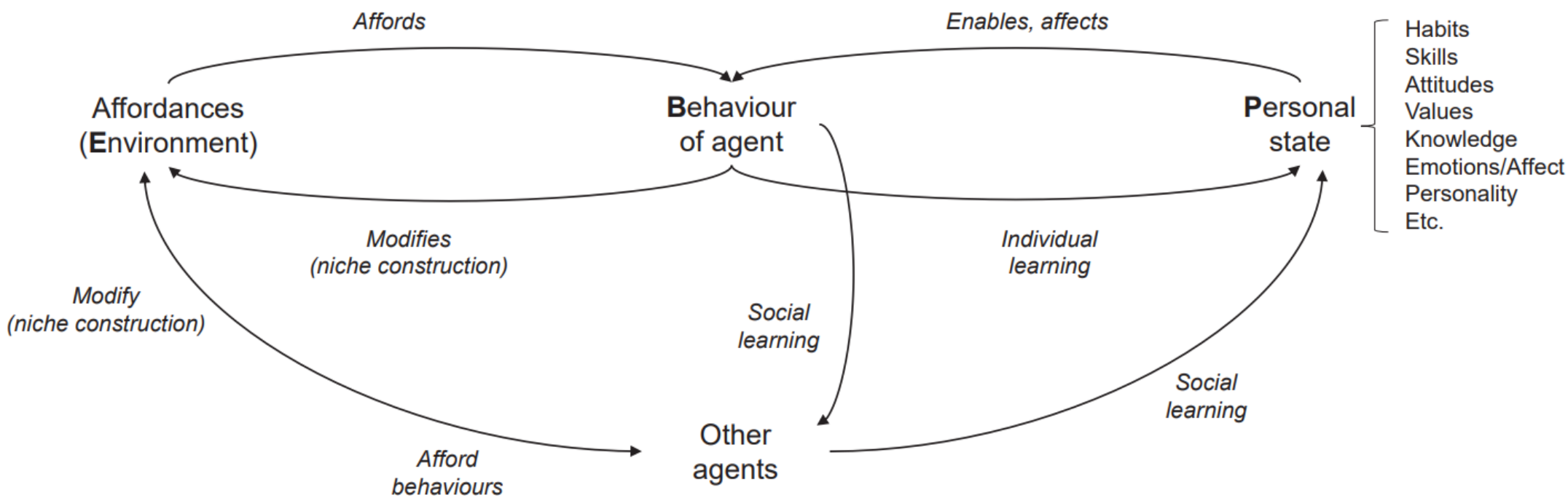
Kurt Lewin: $B = f(P, E)$

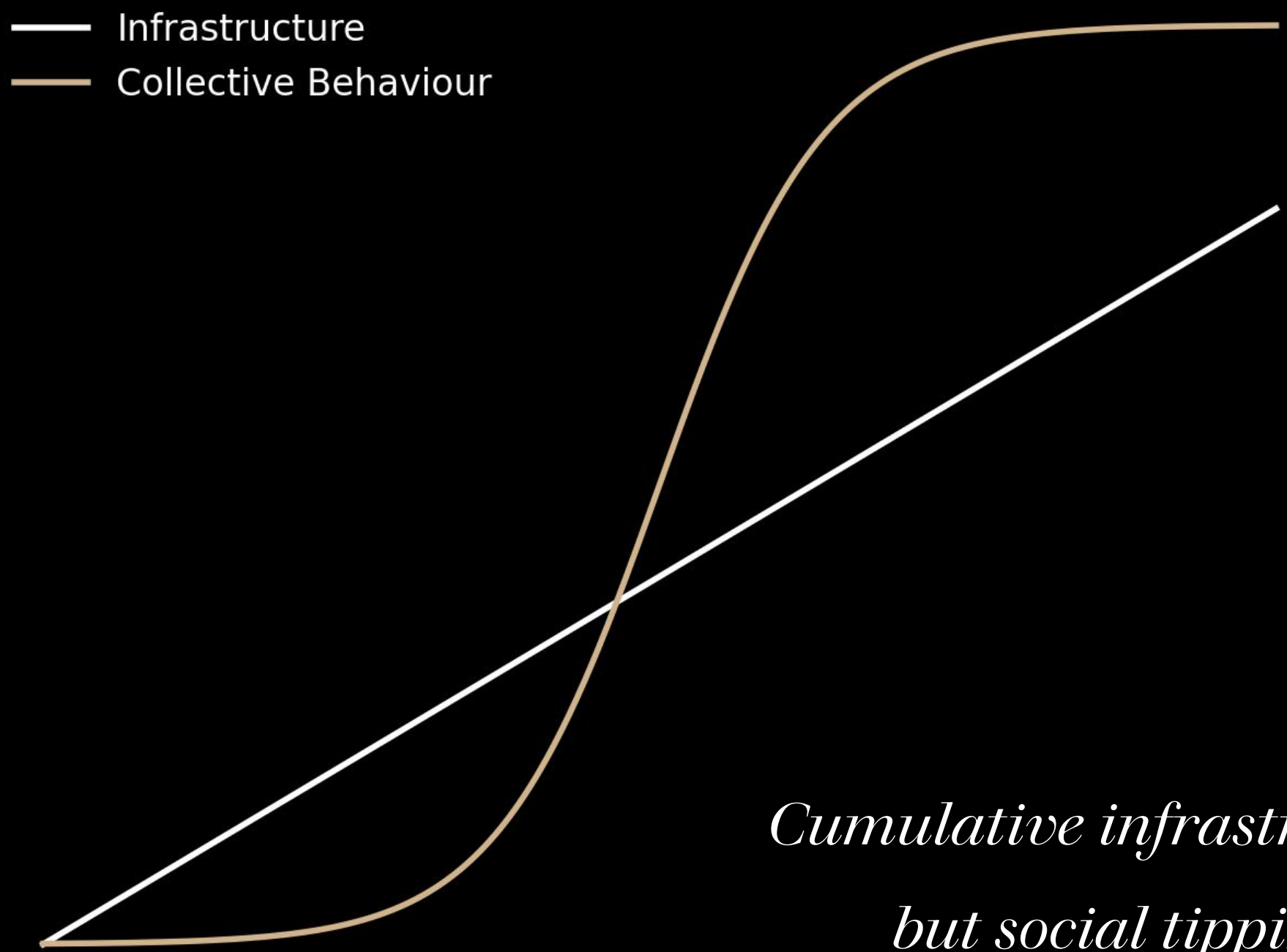
Table 1. Model Assumptions

Description	Causality	Theories and Evidence (Non-exhaustive)
Ecological information specifies a variety of opportunities for behavior, or "affordances"	$E \rightarrow B$	ecological psychology and affordance theory,[1,4,34,35] behavior field theory,[35] and design theories[36]
Personal states affect behavior	$P \rightarrow B$	theory of planned behavior,[7] habituation,[37] and capability approach[38]
Behavior modulates personal states	$B \rightarrow P$	habituation,[37] individual (or asocial) learning,[11,39] cognitive dissonance and self-justification,[5,40,41] and the foot-in-the-door effect[40]
Behavior shapes the environment	$B \rightarrow E$	niche construction and cultural niche construction[9,10] and cumulative cultural evolution[42]
Behavior occurs in a social network with social learning, transmission, and cognition	$B_{(self)} \rightarrow P_{(others)}$, $B_{(others)} \rightarrow P_{(self)}$	social learning,[10,11,39] social cognition,[43] spread of innovation in social networks,[44] group conformity and social norms,[45] and cumulative cultural evolution[42]

This table elaborates on Lewin's equation (Equation 1), where behavior (B) is a function of person (P) and environment (E).

Elaborating Lewin's equation, B = f(P, E)





Cumulative infrastructure,

but social tipping.


GAZELLE
GAZELLE

Image: Pekka Tahkola

Urban niche construction matters.

Can have nonlinear effects on human behavior.

Can ‘tip’ social systems from one state to another.

(But not ‘for free’.)

THANK YOU.

Roope Kaaronen

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Suomen Akatemia
Finlands Akademi
Research Council of Finland