Andrea Bender – Francesco d'Errico – Russell Gray – Rafael Núñez

QUANTA

Evolution of Cognitive Tools for Quantification

Diversity & Synergy

How we got there and what we do with it ...

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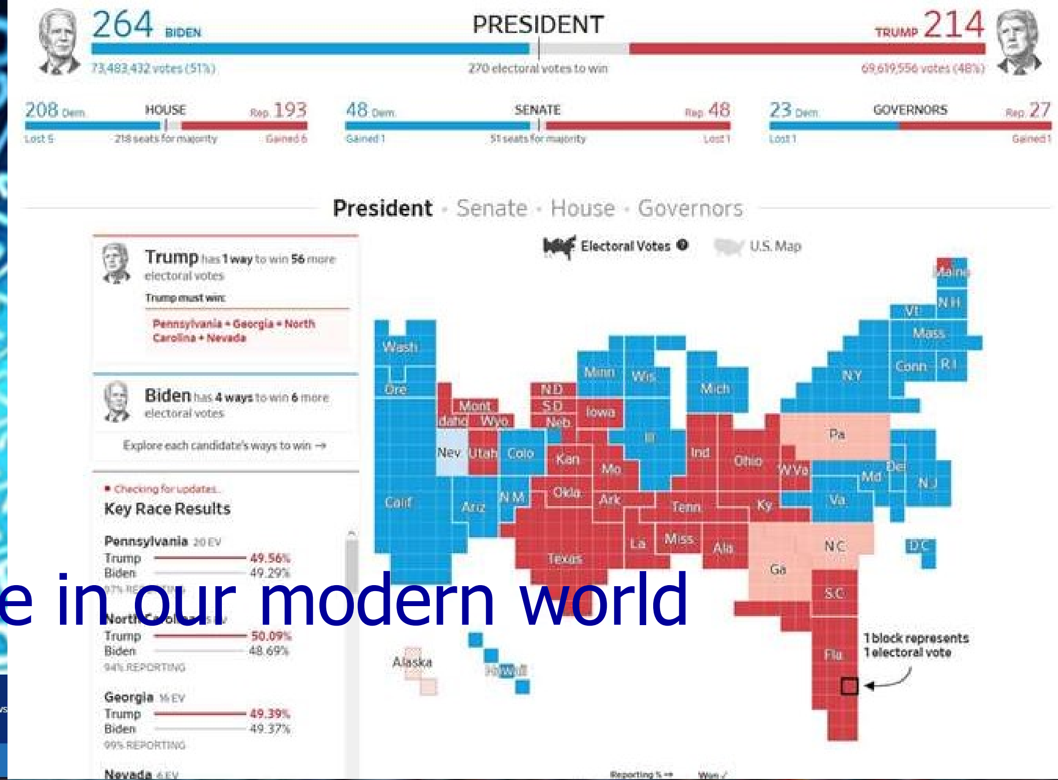
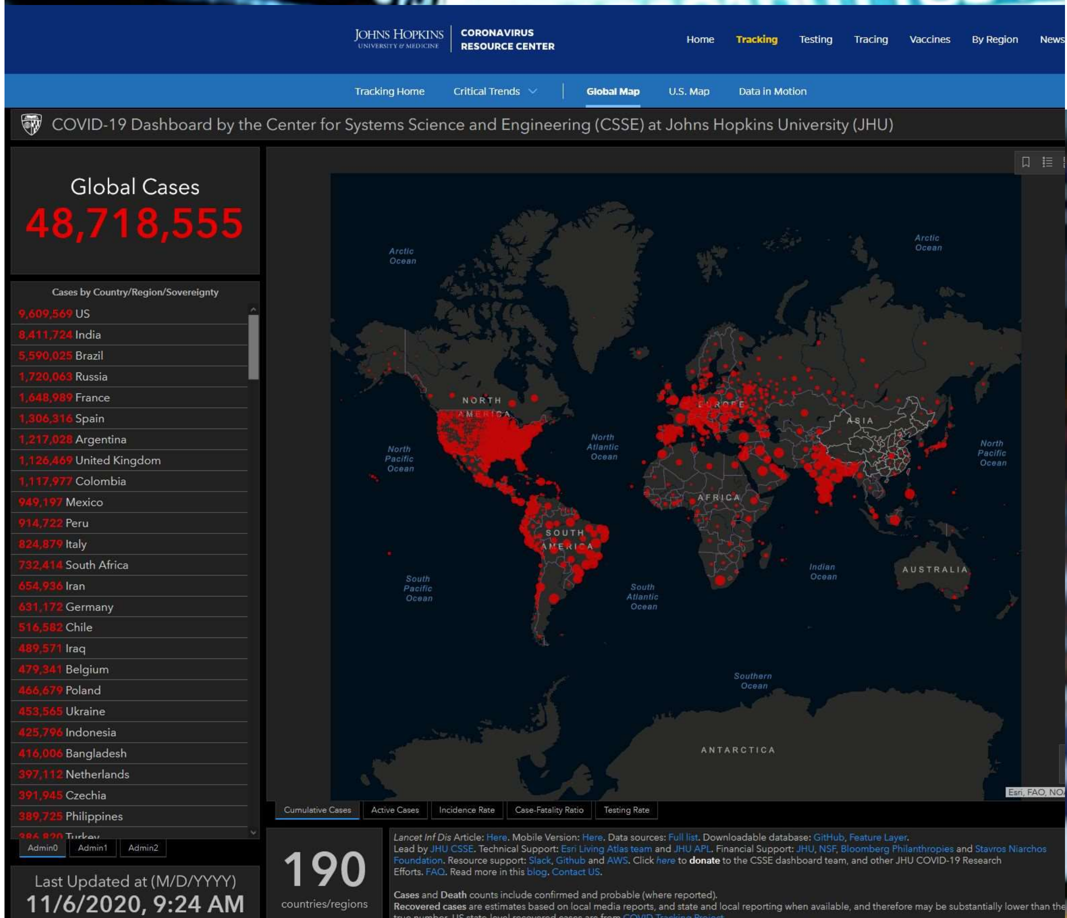
Numbers

… are everywhere in our modern world

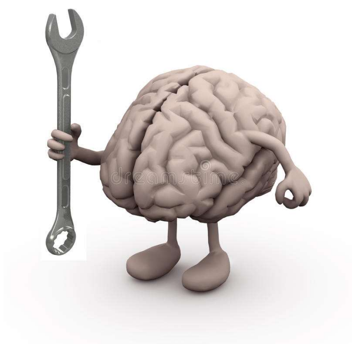


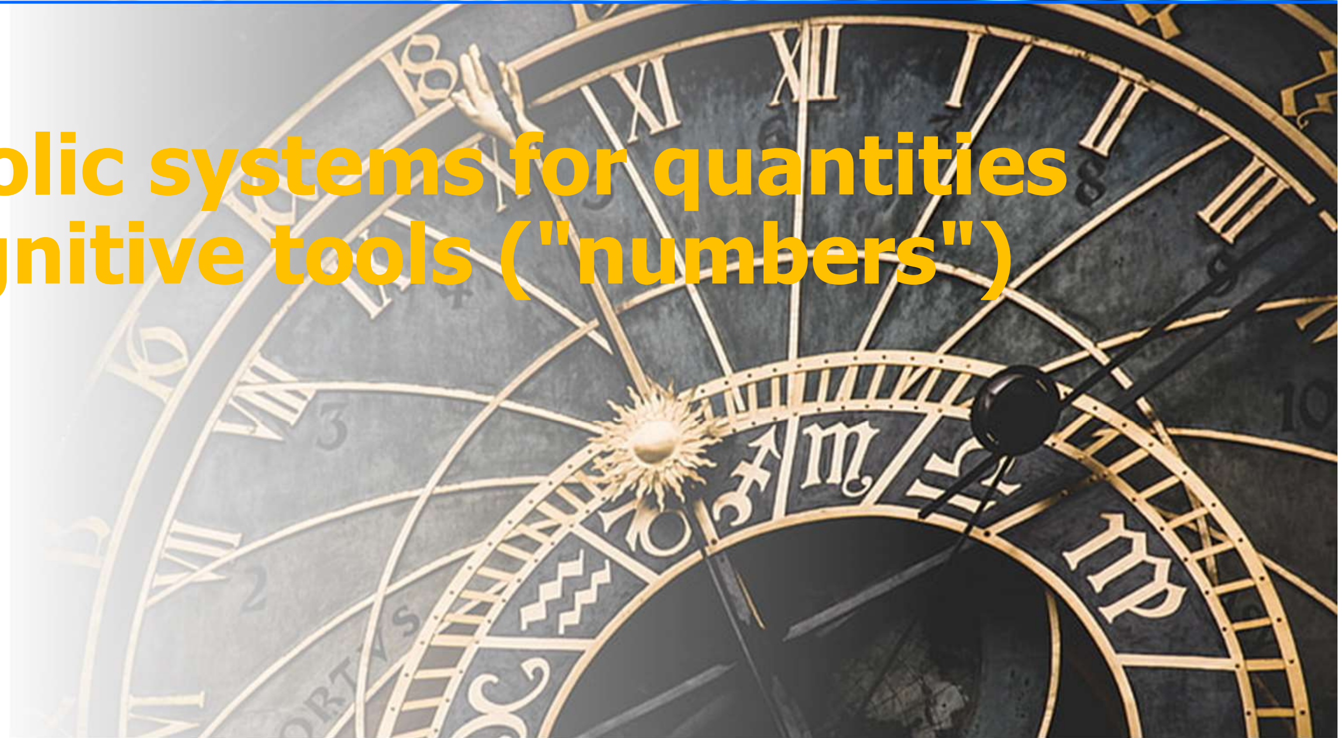


Numbers

… are everywhere in our modern world

… need to be invented





Symbolic systems for quantities as cognitive tools ("numbers")

https://monochrome-watches.com/why-do-clocks-and-watches-use-roman-numeral-iiii-instead-of-iv/

Numbers

1	**I**
2	II
3	III
4	IV
5	**V**
6	VI
7	VII
8	VIII
9	IX
10	**X**
11	XI
12	XII
…	…
50	**L**
60	LX
70	LXX
…	…
100	**C**
500	**D**
1000	**M**
base 10	base 10 & subbase 5

60 sec	= 1 min
60 min	= 1 hour
24 hours	= 1 day
7 days	= 1 week
28-31 days	= 1 month
365 days	= 1 year
12 months	= 1 year
…	

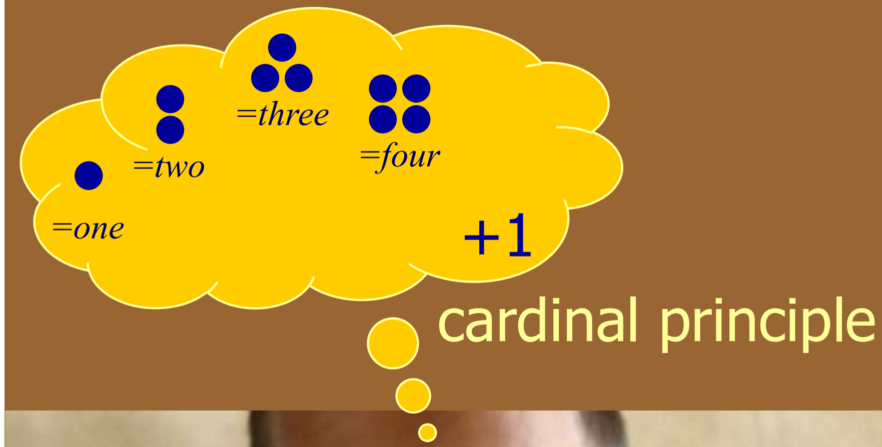
… are everywhere in our modern world

… need to be invented

… occur in striking diversity

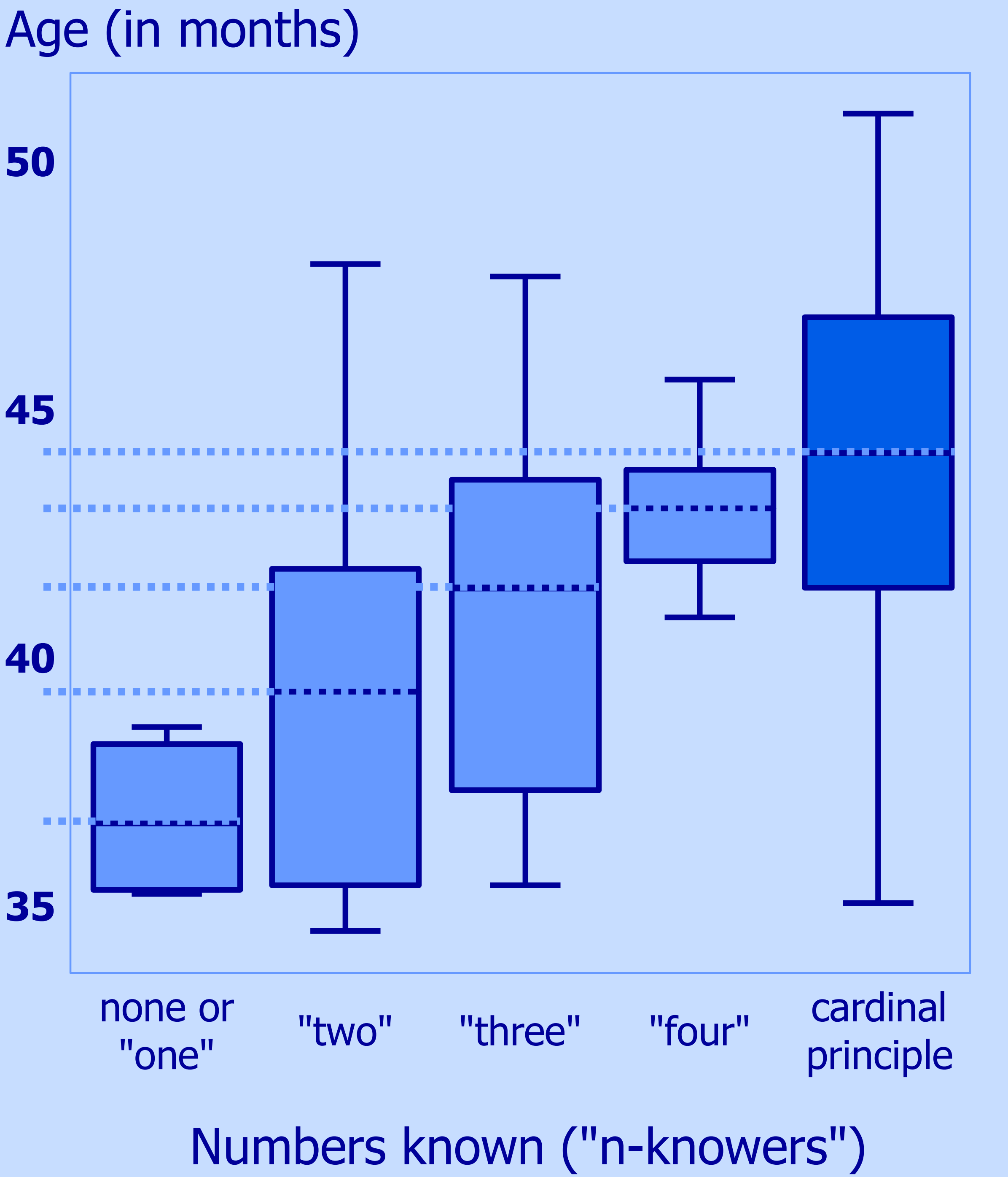
… are essential for numerical cognition

½ 3rd (20)	halvtreds	50 = cinquante	[5 · 10]
3	tres	60 = soixante	[6 · 10] = [60]
½ 4th (20)	halvfjerds	70 = soixante-dix	[60 + 10]
4	firs	80 = quatre-vingt	[4 · 20]
½ 5th (20)	halvfems	90 = quatre-vingt-dix	[4 · 20 + 10]

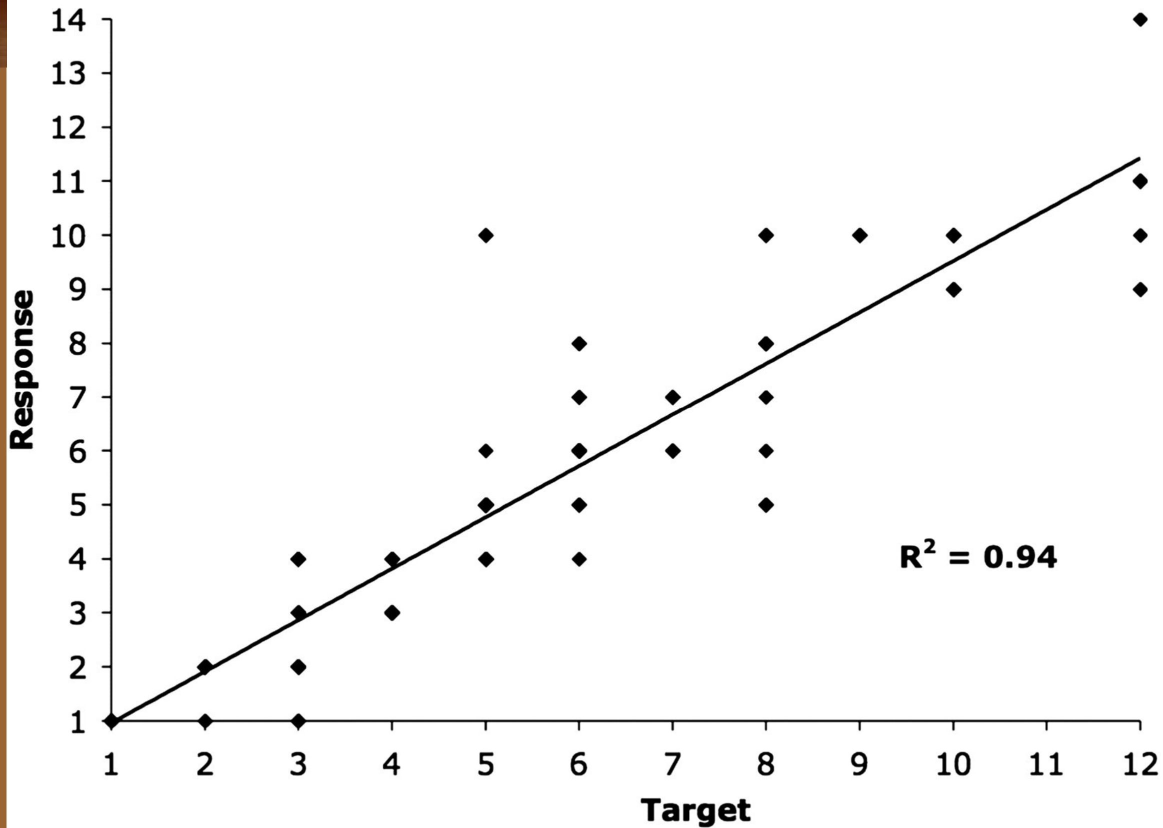


Verbal numeral list
embedded in a count routine

*“one, two, three, four, five,
six, seven, eight …”*



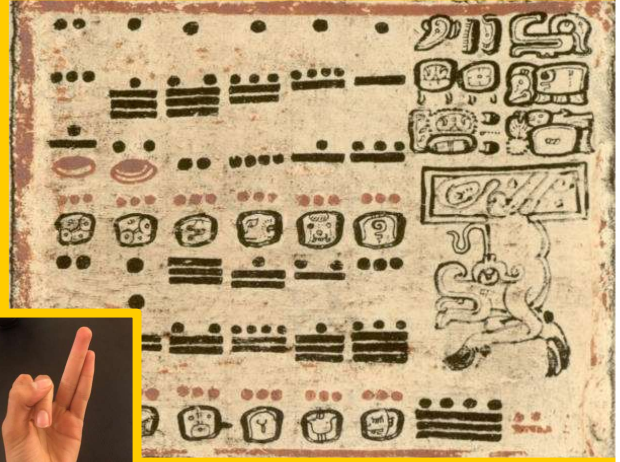
Sarnecka, B. W., & Carey, S. (2008). How counting represents number:
What children must learn and when they learn it. *Cognition*, *108*, 662-674.

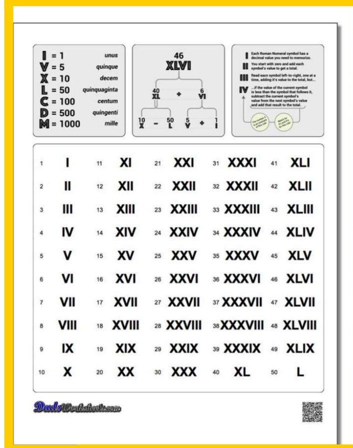


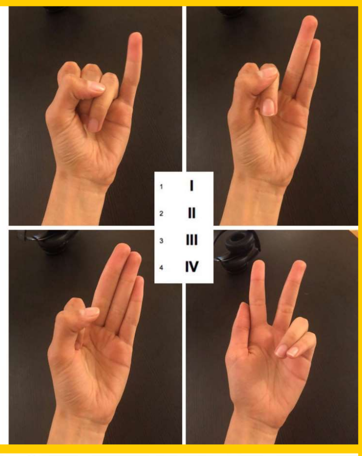
Teaching is essential for understanding number concepts.

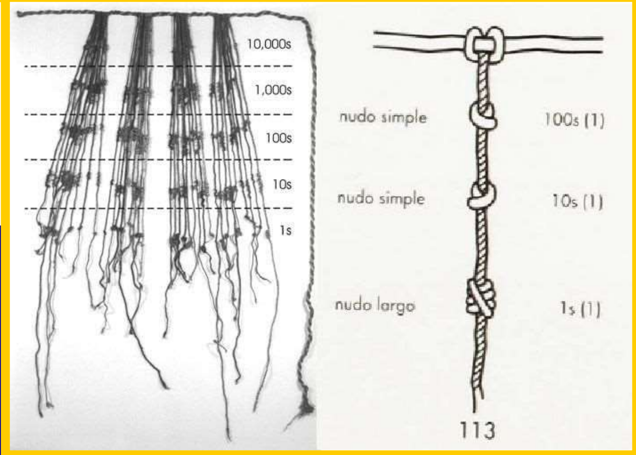
"even when integrated into a numerate society, individuals who lack input from a conventional language do not spontaneously develop representations of large exact numerosities"

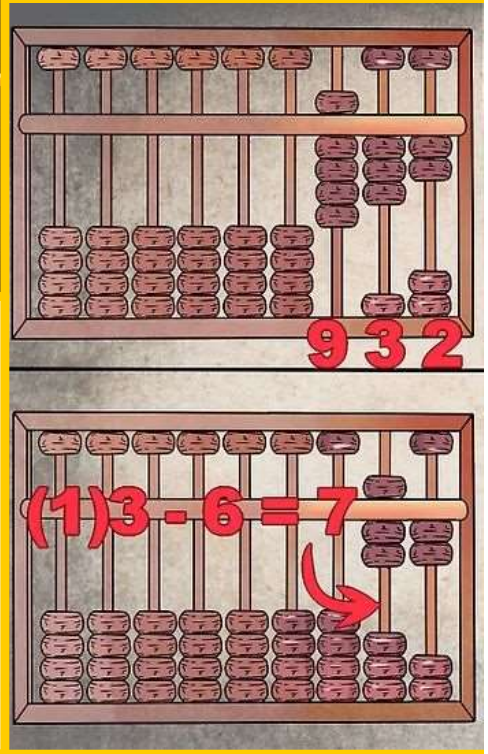
Spaepen, E., Coppola, M., Spelke, E. S., Carey, S. E., & Goldin-Meadow, S. (2011). Number without a language model. *Proceedings of the National Academy of Sciences*, *108*, 3163-3168.











The paradox

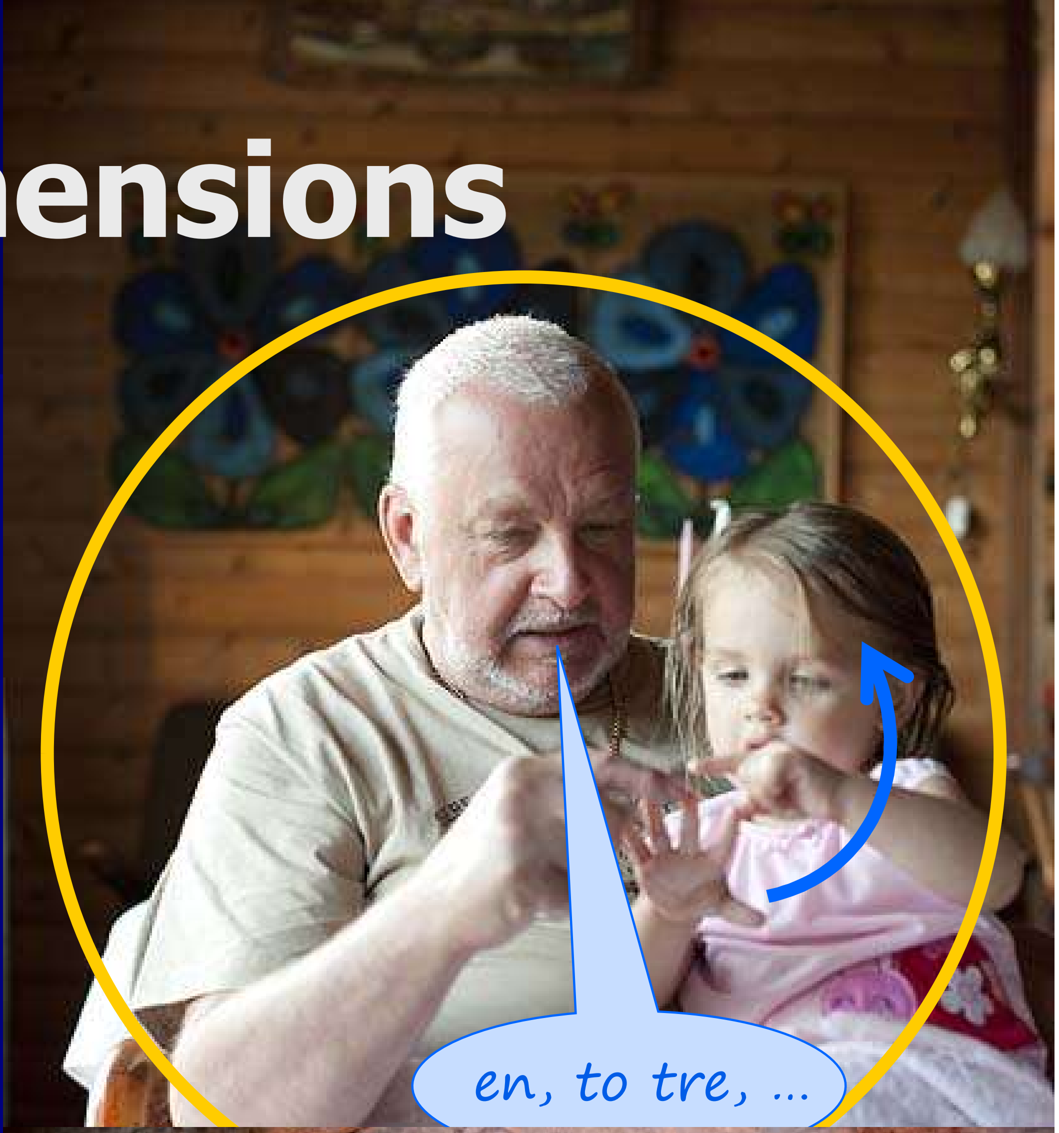
When,
why,
and how
did humans
invent
these tools?

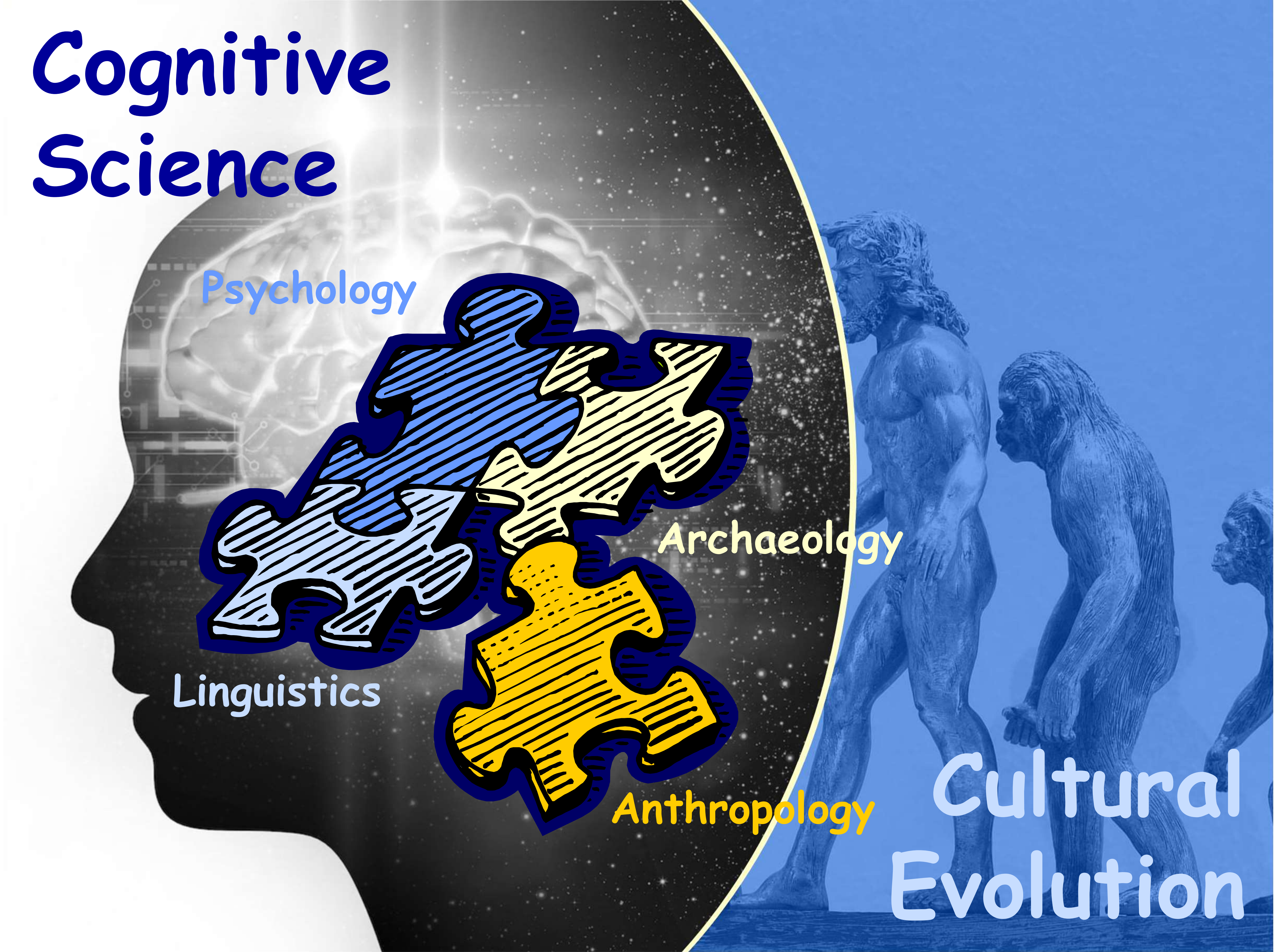
And why do they
differ so massively
across cultures?

Multiple dimensions

Number representations

- ❖ crucial as cognitive tools
- ❖ encoded in language
- ❖ culturally mediated and transmitted
- ❖ represented (& preserved) in artifacts

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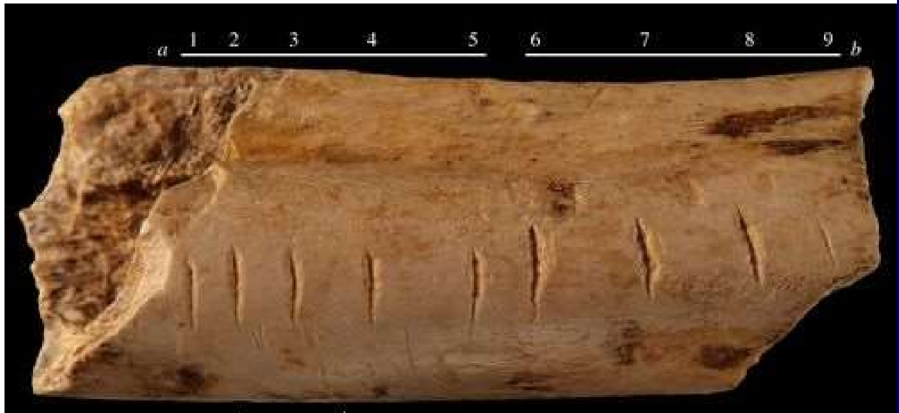

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Research

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One contribution of 19 to a discussion meeting issue 'The origins of numerical abilities'.

Subject Areas:
cognition, evolution, neuroscience

Keywords:
Palaeolithic, counting devices, Neanderthal, Middle Stone Age, confocal microscopy, experimental archaeology

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Electronic supplementary material is available online at https://dx.doi.org/10.6084/m9.figshare.c.3931915.

THE ROYAL SOCIETY

From number sense to number symbols. An archaeological perspective

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How and when did hominins move from the numerical cognition that we share with the rest of the animal world to number symbols? Objects with sequential markings have been used to store and retrieve numerical information since the beginning of the European Upper Palaeolithic (42 ka). An increase in the number of markings and complexity of coding is observed towards the end of this period. The application of new analytical techniques to a 44–42 ka old notched baboon fibula from Border Cave, South Africa, shows that notches were added to this bone at different times, suggesting that devices to store numerical information were in use before the Upper Palaeolithic. Analysis of a set of incisions on a 72–60 ka old hyena femur from the Les Pradelles Mousterian site, France, indicates, by comparison with markings produced by modern subjects under similar constraints, that the incisions on the Les Pradelles bone may have been produced to record, in a single session, homologous units of numerical information. This finding supports the view that numerical notations were in use among archaic hominins. Based on these findings, a testable five-stage scenario is proposed to establish how prehistoric cultures have moved from number sense to the use of number symbols.

This article is part of a discussion meeting issue 'The origins of numerical abilities'.

1. Introduction

The ability to use symbol systems for numbers is peculiarly human. Present-day lifestyle in developed societies is unthinkable without such symbolic systems. We use numbers in virtually every domain, from kitchen to high-tech science laboratories. Systems of notation, mainly in the form of tallies, have a remote history. So-called place-value systems developed in Mesopotamia only about 3.4 ka. Beneath human ability to implement symbolic systems for numbers, however, there are cognitive abilities that we share with several other animal species. A large body of experimental evidence shows that many non-human animal species are capable of processing numerical information [1–5]. These abilities mainly have to do with estimating magnitudes (length, duration, luminance, approximate amount of something, etc.) in an approximate manner. Many contributions to this special issue address this point and report about the cognitive and neural evidence that we share a 'number sense' [6] with other animal species.

When processing this kind of information, human and non-human animals are submitted to the same cognitive constraints predicted by the Weber law [7], which states, in short, that when comparing two different magnitudes, the chances of getting the difference right decrease with a reduction of the

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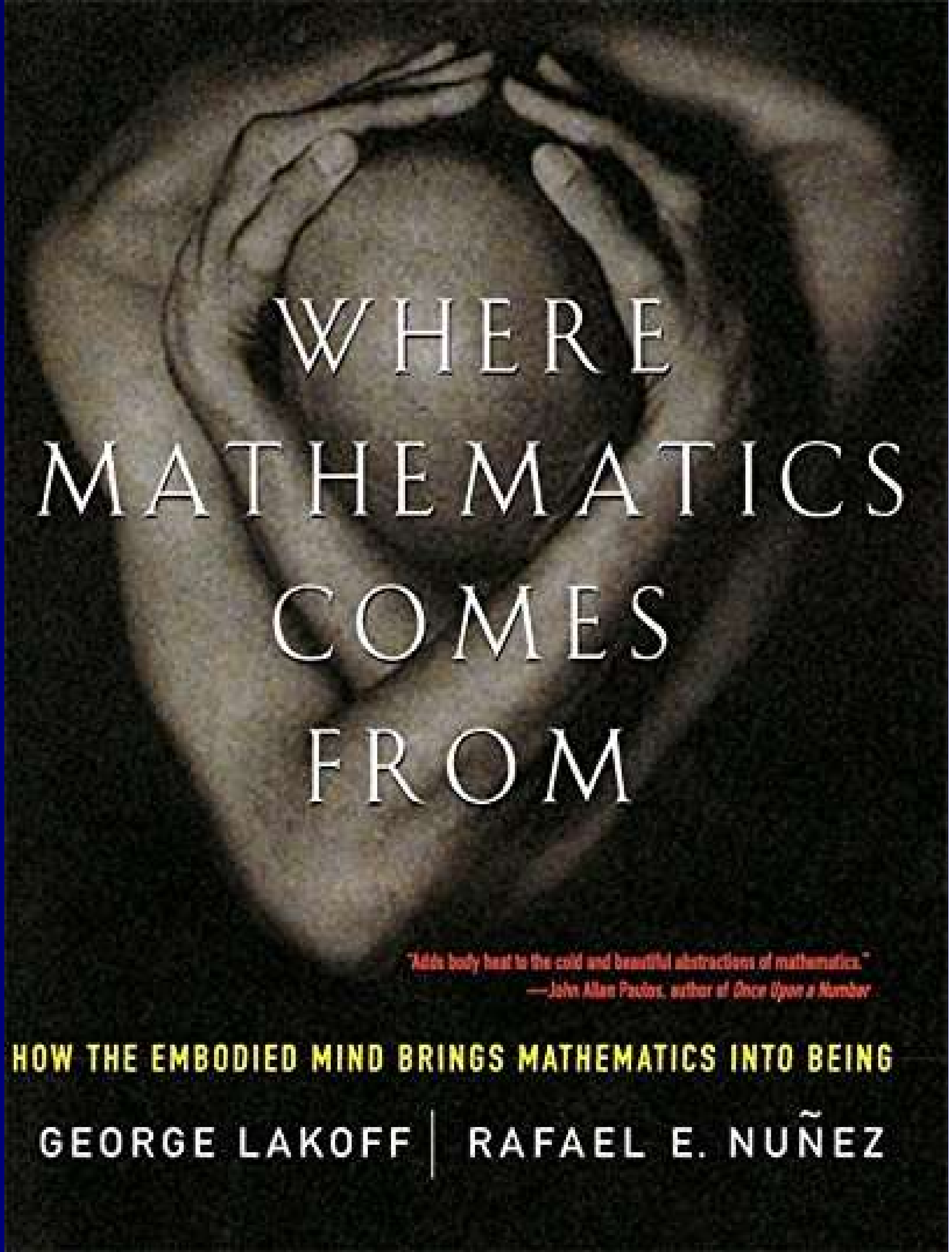

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Review

Trends in Cognitive Sciences March 2012, Vol. 16, No. 3

Tools from evolutionary biology shed new light on the diversification of languages

Stephen C. Levinson[1,2] and Russell D. Gray[3]

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[2] Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, Kapittelweg 29, 6525 EN Nijmegen, The Netherlands
[3] Department of Psychology, University of Auckland, Auckland 1142, New Zealand

Computational methods have revolutionized evolutionary biology. In this paper we explore the impact these methods are now having on our understanding of the forces that both affect the diversification of human languages and shap
these methods ca
the nature of cons
role that social pro
linguistic change.
the cognitive scien
ized model of hun
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Variation is the ke
Evolutionary scient
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[1]. Variation is the
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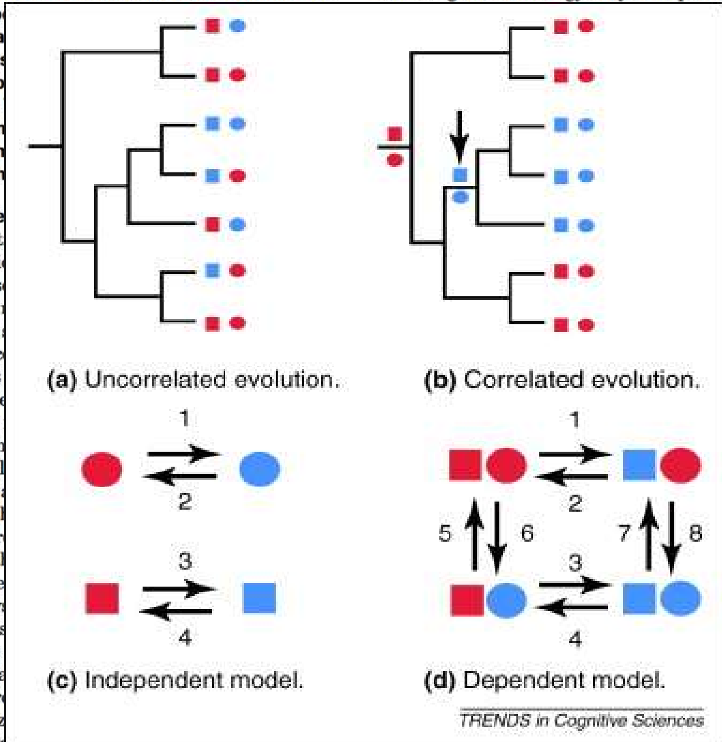
ing this diversity as
we argue that this
standing the crucia
that tools derived fr
new ways of analyz
Why do language
noting the curious parallels between languages and species, and indeed similar processes of speciation, drift, and adaptation can be observed in the language domain. Processes of group boundary formation account for change under demographic pressures, drift accounts for change

by geographic or social isolation, and adaptation for the changes that can be observed as languages reflect the cultural uses to which they are put (with e.g. color words reflecting the technology of dye and paint [6], kinship terms
heritance [7], and
of literacy and its

ugh there is much
l insight). What is
t of highly sophis-
these processes of
e possible is the
rocesses from the
is is time travel of
amed of. The tools
gy, and although
phylogenetic rela-
ology, they allow
any kind of struc-
ionary processes,
low, for example,
l assemblages [9],
itive processes by

tools can be illus-
ntral question in
liversification and
nstraints? Gener-
assumed that the
uages is universal,
nd variation may
ameters' or binary
s multiply out the
typologists follow
strong tendencies for specific features to clump together, so limiting variation. A classic example in both approaches is word order. Greenberg noted that in a sample of 30 languages the position of the verb vis-à-vis its object seems to control other word order features, especially the order of adpositions (prepositions if before the noun, postpositions if after), and other nominal elements like adjectives and determiners. A worldwide



(a) Uncorrelated evolution.
(b) Correlated evolution.
(c) Independent model.
(d) Dependent model.

Corresponding author: Levinson, S.C. (stephen.levinson@mpi.nl).

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The Limits of Counting: Numerical Cognition Between Evolution and Culture
Sieghard Beller, *et al.*
Science **319**, 213 (2008);
DOI: 10.1126/science.1148345

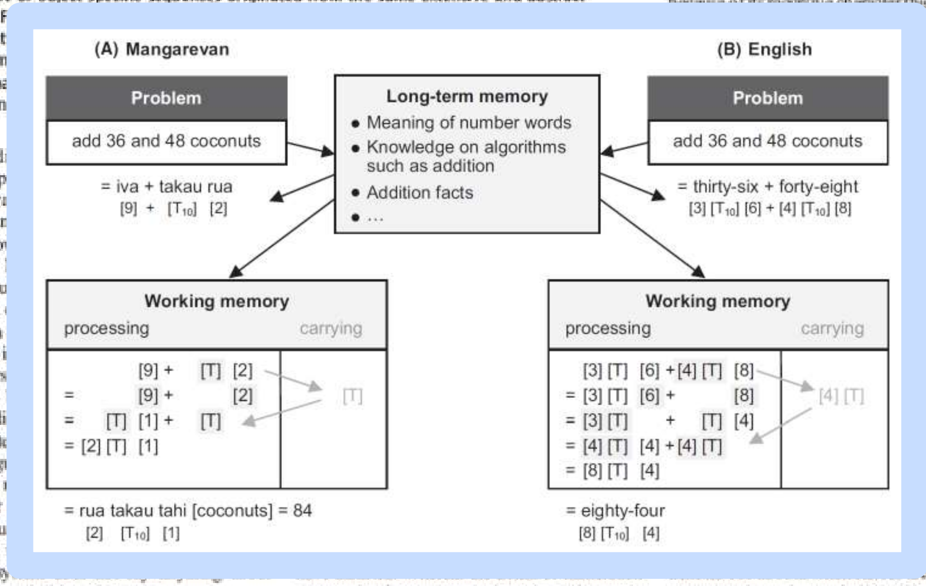
The Limits of Counting: Numerical Cognition Between Evolution and Culture

Sieghard Beller and Andrea Bender*

Number words that, in principle, allow all kinds of objects to be counted ad infinitum are one basic requirement for complex numerical cognition. Accordingly, short or object-specific counting sequences in a language are often regarded as earlier steps in the evolution from premathematical conceptions to greater abstraction. We present some instances from Melanesia and Polynesia, whose short or object-specific sequences originated from the same extensive and abstract sequence. F… for calculat… higher num… results expa… numeration…

The d… or p… mera… Amazonian… sion of how… language. … tools for nu… perimental … provided a … such tools i… of numbers… eral, may … spective di… demonstrat… purely ling… should be … of whether … on the natu… usage and … meration sy… the cognitive abilities of its users.

Apart from their efficiency, cognitive tools can also be ordered according to their presumed evolution. Because tools are typically developed in order to improve their efficiency, it is reasonable to assume that numeration systems evolve from being simpler to more sophisticated (*6*, *13*–*15*). But can one also conclude that the simpler a numeration system, the older it is? Although the … systems has been extensively addressed recently (*1*, *2*, *12*), the degree of abstractness has largely been neglected so far. We will illustrate these properties with two instances for each but will focus on the second feature.

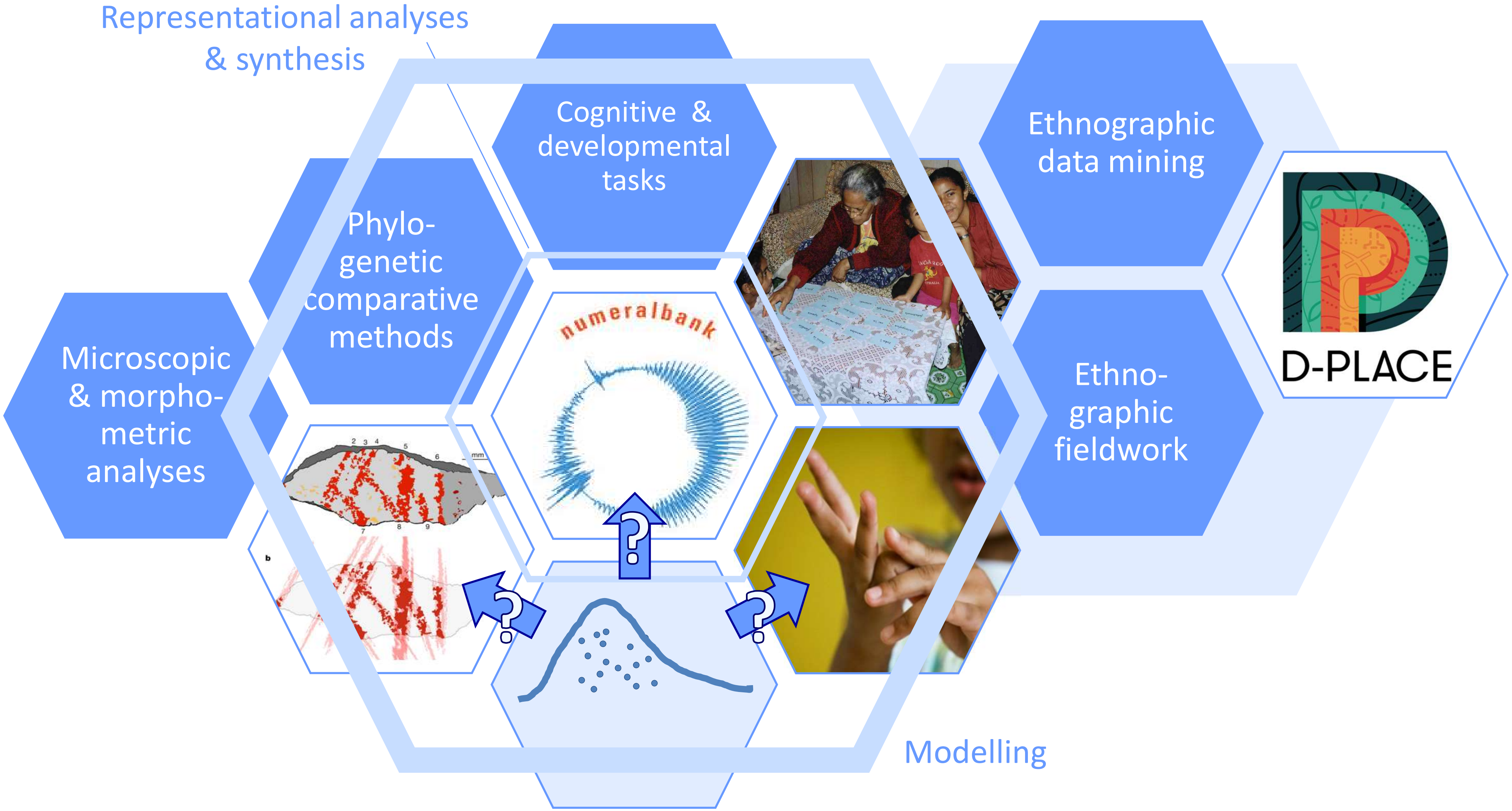


One region where systems with limited extent abound is Papua New Guinea (*16*). Takia, a language in Madang Province, contains five numerals—*kaik*, *uraru*, *utol*, *iwaiwo*, and *kafe-n* (also denoting "his/her thumb"). Higher numbers may be composed by adding or multiplying numerals to the word for 5, but this seems to have been done rarely and for low numbers only (*17*). Adzera, a related language in the Markham River valley in Morobe Province, contains an even more restricted system. Its number words for 1 to 5 are composed of numerals for 1 and 2 only: *bits*, *iru'*, *iru' da bits* (= 2 + 1), *iru' da iru'* (= 2 + 2), and *iru' da iru' da bits* (= 2 + 2 + 1). Although … this system is in … fficulties in … words render … e nowadays … sin instead, a … and used as … e admittedly … system, but … er powers of … lthough nu… Melanesian … imentally, it … ith such re… l operations … le, for larger … lily taken as … numeration … Menninger … fic counting … more anti… *14*). One of … such object… igh Fijian, a … Whereas it … counted, for coconuts *koro* is used (*20*). Similar object-specific counting sequences can be found in the related Polynesian languages. On Mangareva, for instance, a volcanic island group in French Polynesia, tools, sugar cane, pandanus, breadfruit, and

Table 1. Numerals in traditional Mangarevan (abstract sequence).

Single numerals				Power numerals (quantities)			
1	tahi	6	ono	10^1	rogo'uru	$2 \cdot 10^5$	makiukiu
2	rua	7	hitu	$2 \cdot 10^1$	takau	$2 \cdot 10^6$	makore
3	toru	8	varu	$2 \cdot 10^2$	rau	$2 \cdot 10^7$	makorekore
4	hā	9	iva	$2 \cdot 10^3$	mano	$2 \cdot 10^8$	tini
5	rima			$2 \cdot 10^4$	makiu	$2 \cdot 10^9$	maeaea

Department of Psychology, University of Freiburg, D-79085 Freiburg, Germany.
*To whom correspondence should be addressed. E-mail: bender@psychologie.uni-freiburg.de



Representational analyses & synthesis
Cognitive & developmental tasks
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D-PLACE
Modelling

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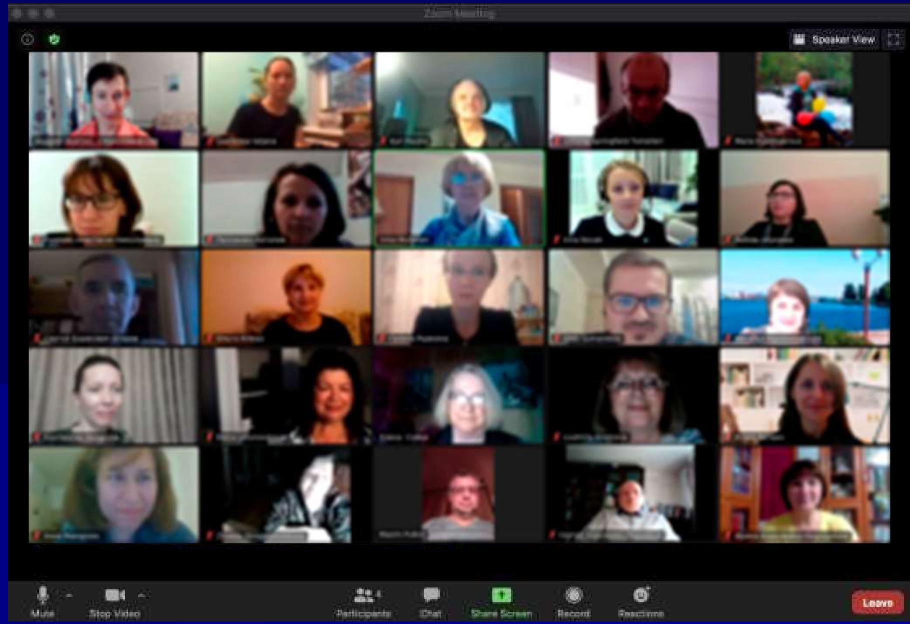
set up "for scientists, by scientists"

- Funding schemes set up **"for scientists, by scientists"**
- Open to top researchers of **any nationality, age and gender, from anywhere in the world**, to perform research in Europe
- Long-term, individual grants for **ground-breaking, high-risk and high-gain research**
- **No thematic priorities**; any fie[...] engineering, life sciences, social sciences and humanities)
- **Bottom-up**, curiosity-driven approach
- Sole selectio[...]
- Selection bas[...]

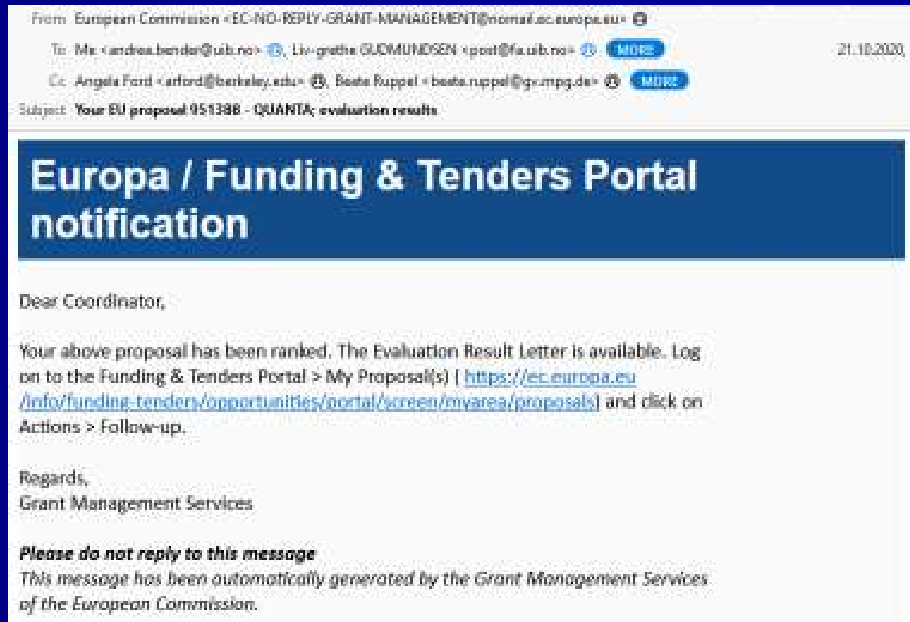
high-risk & high-gain

curiosity-driven research

Our timeline



2017		first ideas, meetings, & plans for proposal
2018		on hold
2019		resuming work on proposal
	Nov 5:	submission
2020	Mar 2:	step 1 passed
	Jun 25:	step 2 passed
	Sep 9:	interview
	Oct 21:	"ranked" (granted)
2021	July 27:	ethics clearance & contract signed
	Sep 1:	official start


From European Commission <EC-NO-REPLY-GRANT-MANAGEMENT@nomail.ec.europa.eu>

To Ms <andrea.bender@uib.no>, Liv-grethe GUDMUNDSEN <post@fa.uib.no> MORE 21.10.2020,

Cc Angela Ford <arford@berkeley.edu>, Beate Ruppel <beate.ruppel@gv.mpg.de> MORE

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Dear Coordinator,

Your above proposal has been ranked. The Evaluation Result Letter is available. Log on to the Funding & Tenders Portal > My Proposal(s) (https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/myarea/proposals) and click on Actions > Follow-up.

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Grant Management Services

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Our timeline & some obstacles

2017		first ideas, meetings, & plans for proposal	
2018		on hold	… life as such
2019		resuming work on proposal	… coordination issues
	Nov 5:	submission	
2020	Mar 2:	step 1 passed	
	Jun 25:	step 2 passed	… covid travel restrictions
	Sep 9:	interview	… via zoom (but no ppt)
	Oct 21:	"ranked" (granted)	
2021	July 27:	ethics clearance & contract signed	… bureaucracy & US/EU
	Sep 1:	official start	… still travel restrictions

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Good luck ☺