Experience Curves: Theory and Practice (…and Strategy)

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Fundamentals less than novel…

For the things we have to learn
before we can do them,
we learn by doing them,
e.g. men become builders by building
and lyreplayers by playing the lyre.

Aristotle, Nicomachean Ethics, Book II, Ch 1

Proceeds to discuss rôle of teacher; implied distinction:

- replicative learning (hygienic);
- constructive learning (strategic).

December 27. - Killed a young goat, and lamed another, so that I catched it, and led it home in a string. When I had it home, I bound and splintered up its leg, which was broke. N.B. - I took such care of it, that it lived; and the leg grew well and as strong as ever; but by my nursing it so long it grew tame, and fed upon the little green at my door, and would not go away. This was the first time that I entertained a thought of breed up some tame creatures, that I might have food when my powder and shot was all spent.

Daniel Defoe—*Robinson Crusoë*[1]

Trial-and-Error ➔ Routine-Error-Trial-and-Discovery…Routine

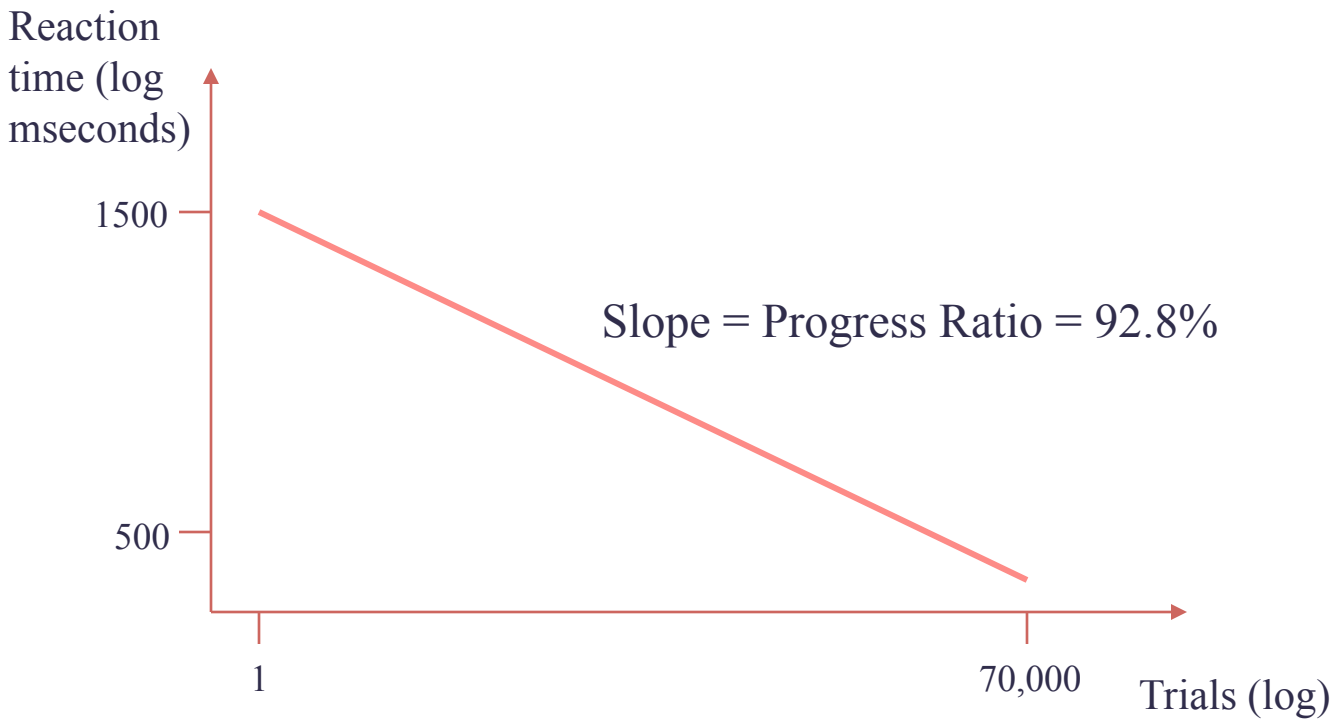
1) Only book Rousseau allows Émile to read in his early education.

Short History of the Experience Curve (I)

1885 Hermann Ebbinghaus – *Über das Gedächtnis*

1894 Lloyd Morgan—*learning by trial-and-error*

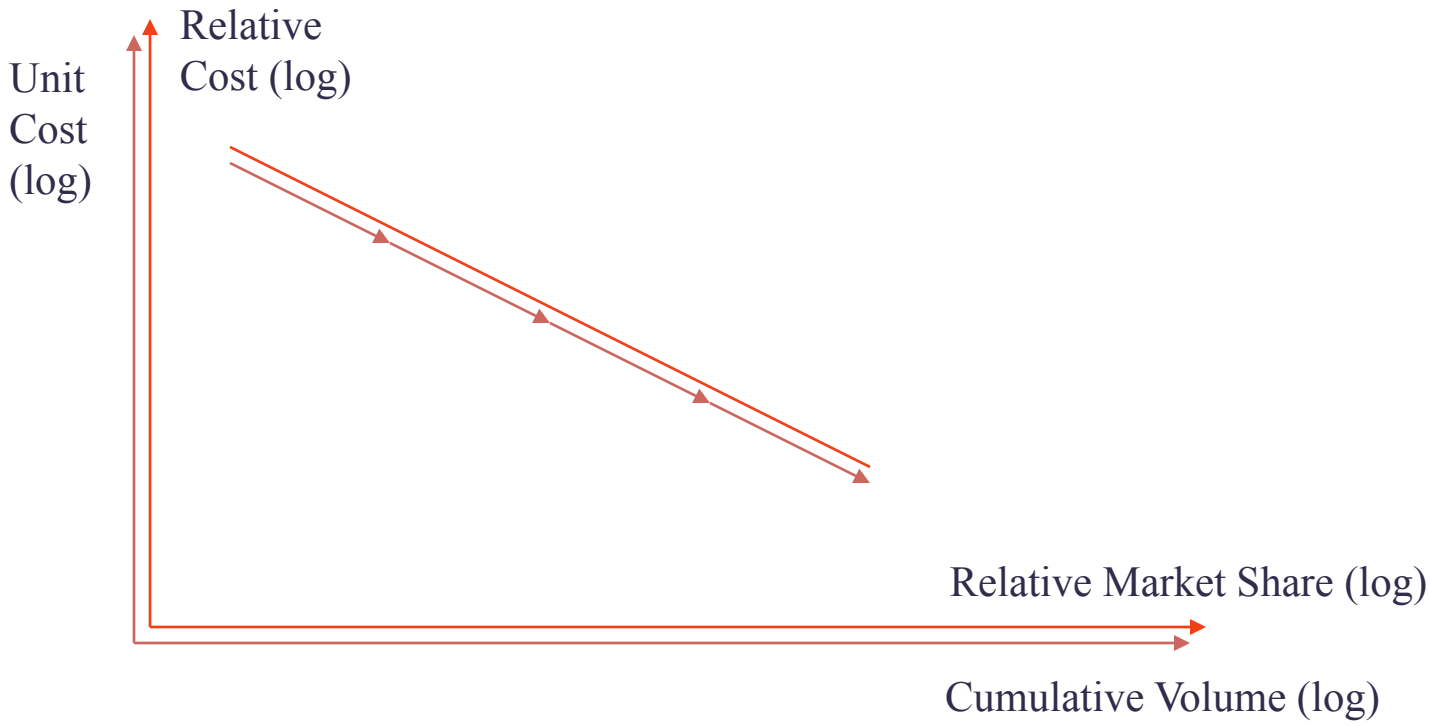
1926 G.S. Snoddy – plotting skill acquisition



Short History of the Experience Curve (II)

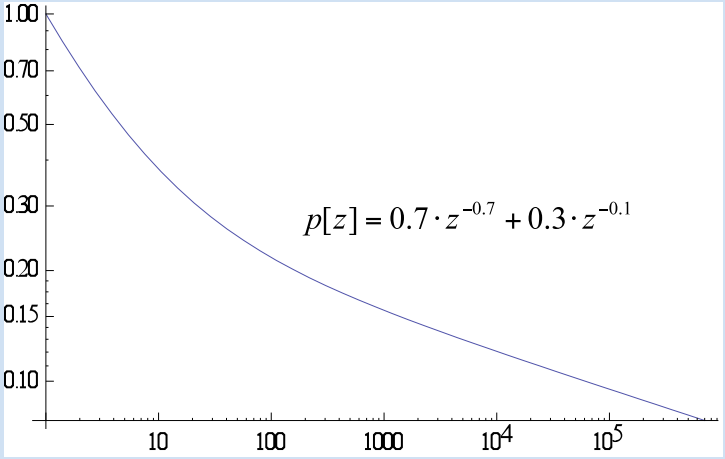
1936 T.P. Wright at Lockheed – *Factors affecting the costs of airplanes*

1966 Bruce Henderson at BCG



Common deviations from power-law

Cost-specific learning

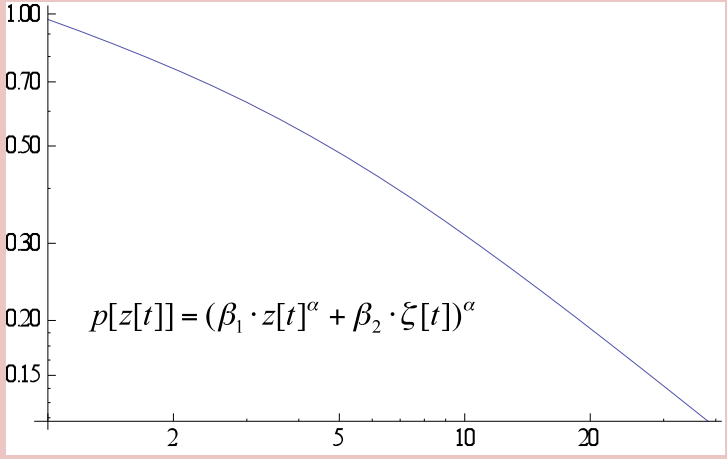


The log-log slope of total cost is the cost-weighted average of the constituent slopes (shallowest slope to dominate eventually):

$$p[z] = \sum_i \beta_i \cdot z^{\alpha_i}$$

$$\frac{p'[z]}{p[z]} \cdot z = \frac{\sum_i \alpha_i \cdot \beta_i \cdot z^{\alpha_i}}{\sum_i \beta_i \cdot z^{\alpha_i}} = \frac{\sum_i w_i \cdot \alpha_i}{\sum_i w_i}, \text{ with } w_i = \sum_i \beta_i \cdot z^{\alpha_i}$$

Shared costs and diverse clocks



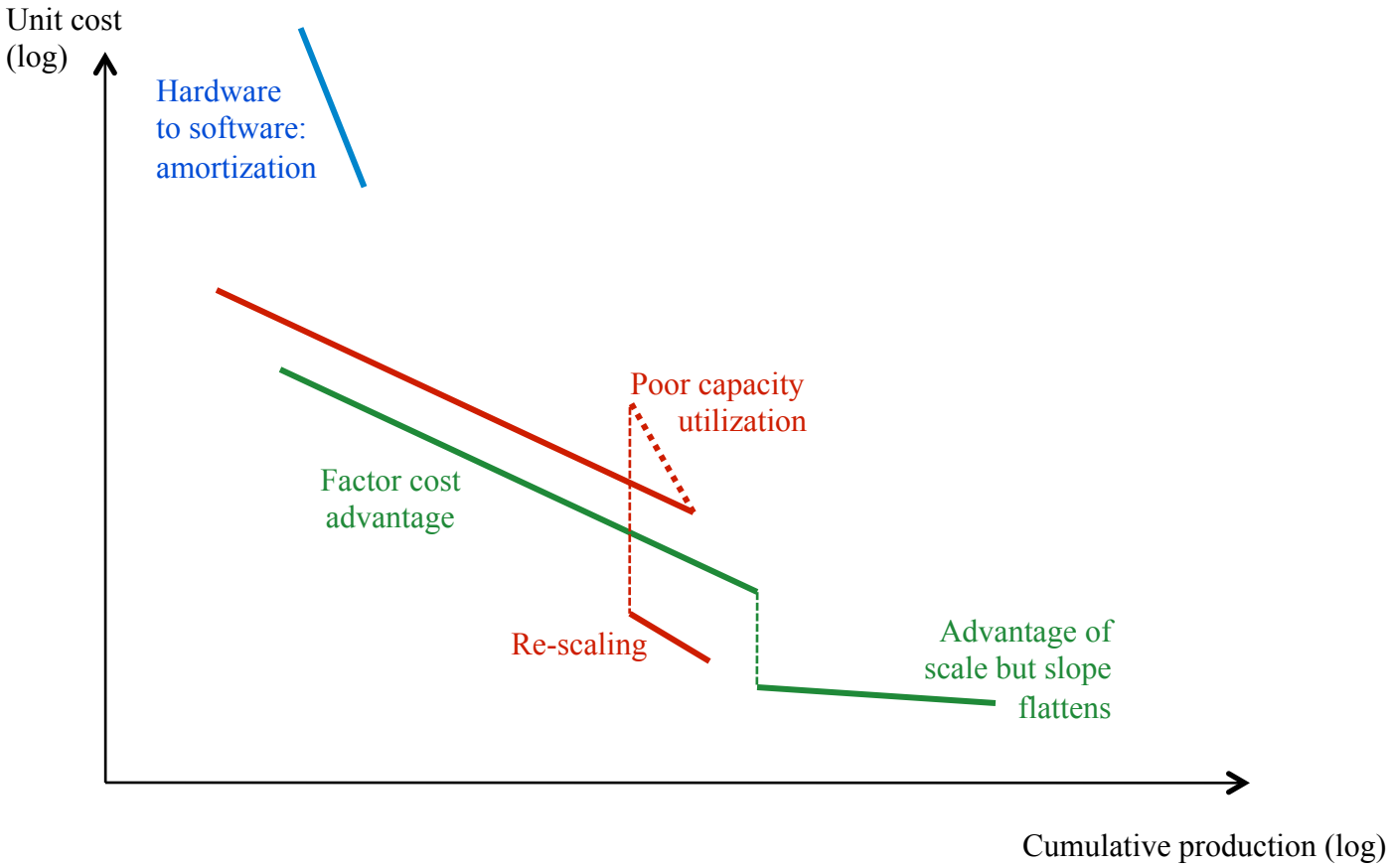
Costs of activity z are shared with an initially small but rapidly growing activity ζ. Essentially a "clock malfunction."

Diverse clocks (e.g.):

- manufacturing;
- advertising;
- R&D.

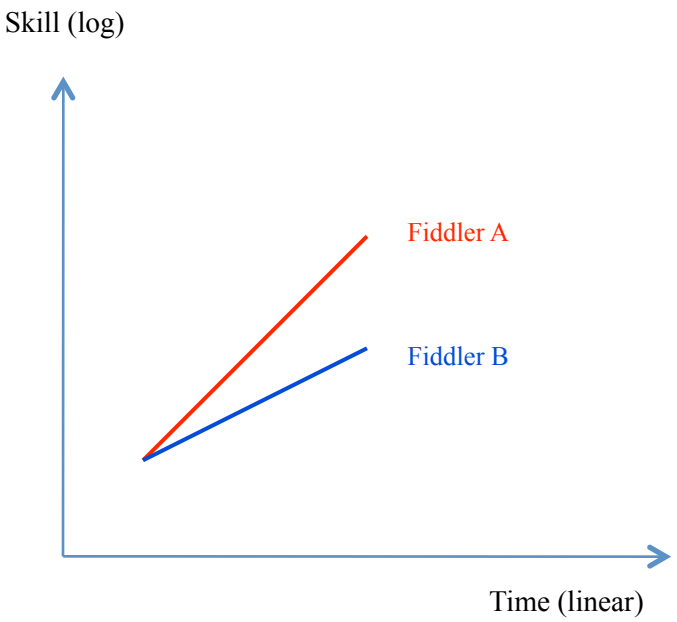
More than one game in town: scale, utilization, amortization…

(specialization/integration, (de-)centralized production, focus/breadth…)

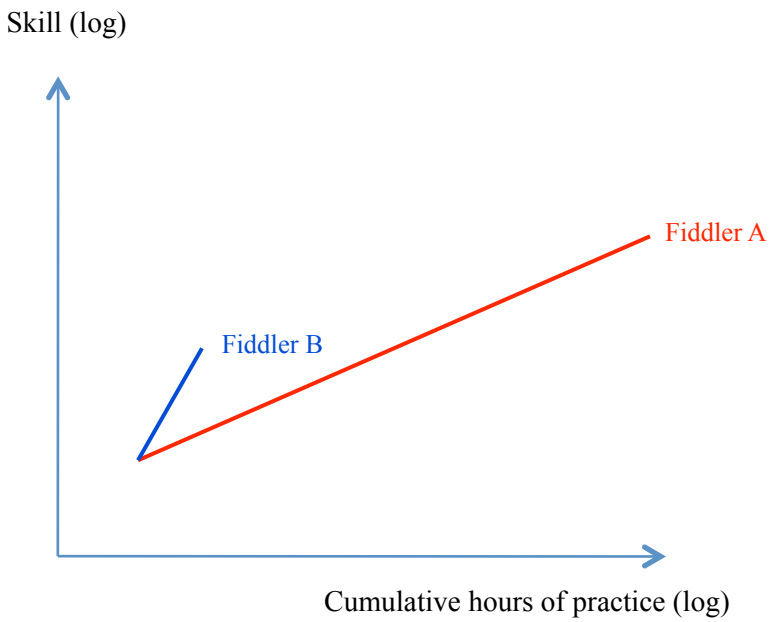


On Moore's "Law" or how to pick a violin virtuoso?

Moore's choice



Wright's choice



The Proper Clock

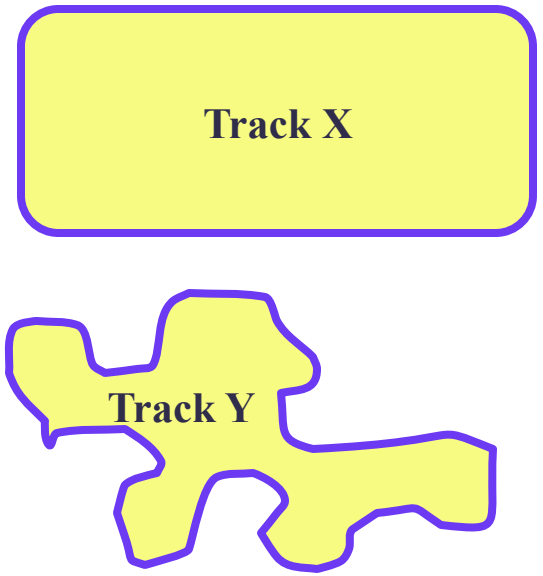
Moore's curve is not a proper framework for assessing progress:

- when experience accumulates in geometic fashion, it is a trivial corollary of Wright's experience curve;
- if there were other cases (none known) where it applied, it would deserve further attention;
- but, in any case, it suggests a causal relationship between performance and calendar time;
- which fails as a "proper clock" to account for the use of resources;
- identifying the proper clock far from obvious in many cases.

Bending the e-curve (1)

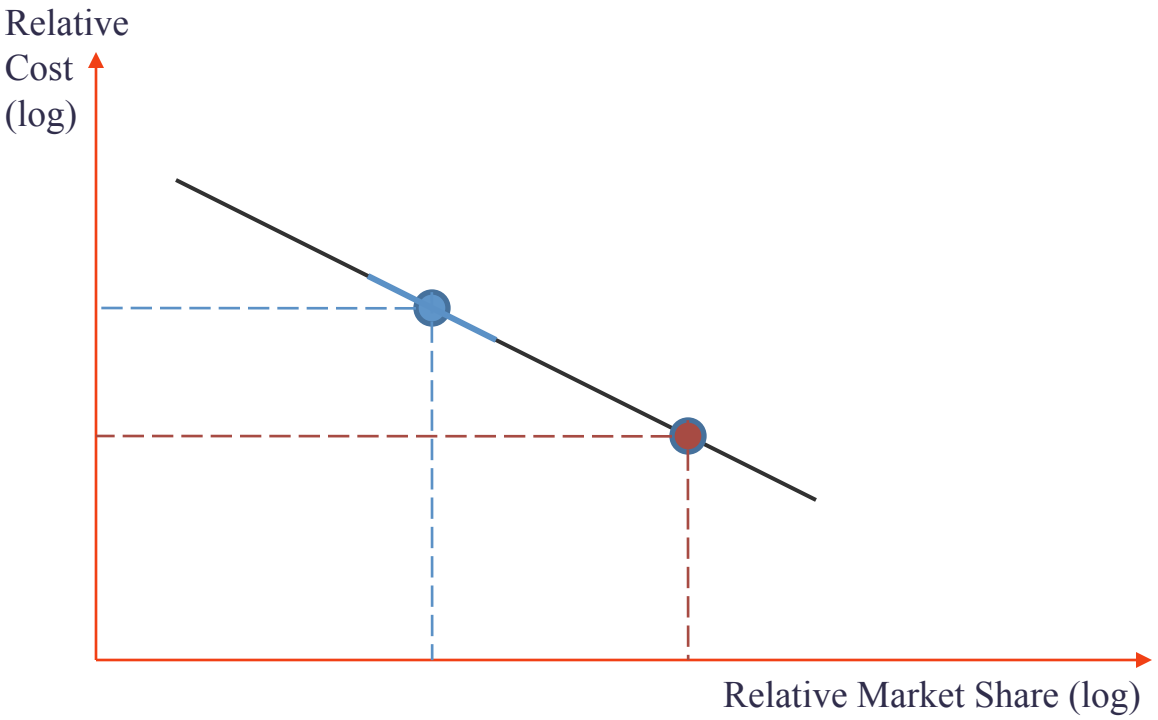
Reason 1: environment

	Max Speed	Acceleration
Car A	250 km/h	5 s
Car B	220 km/h	3 s

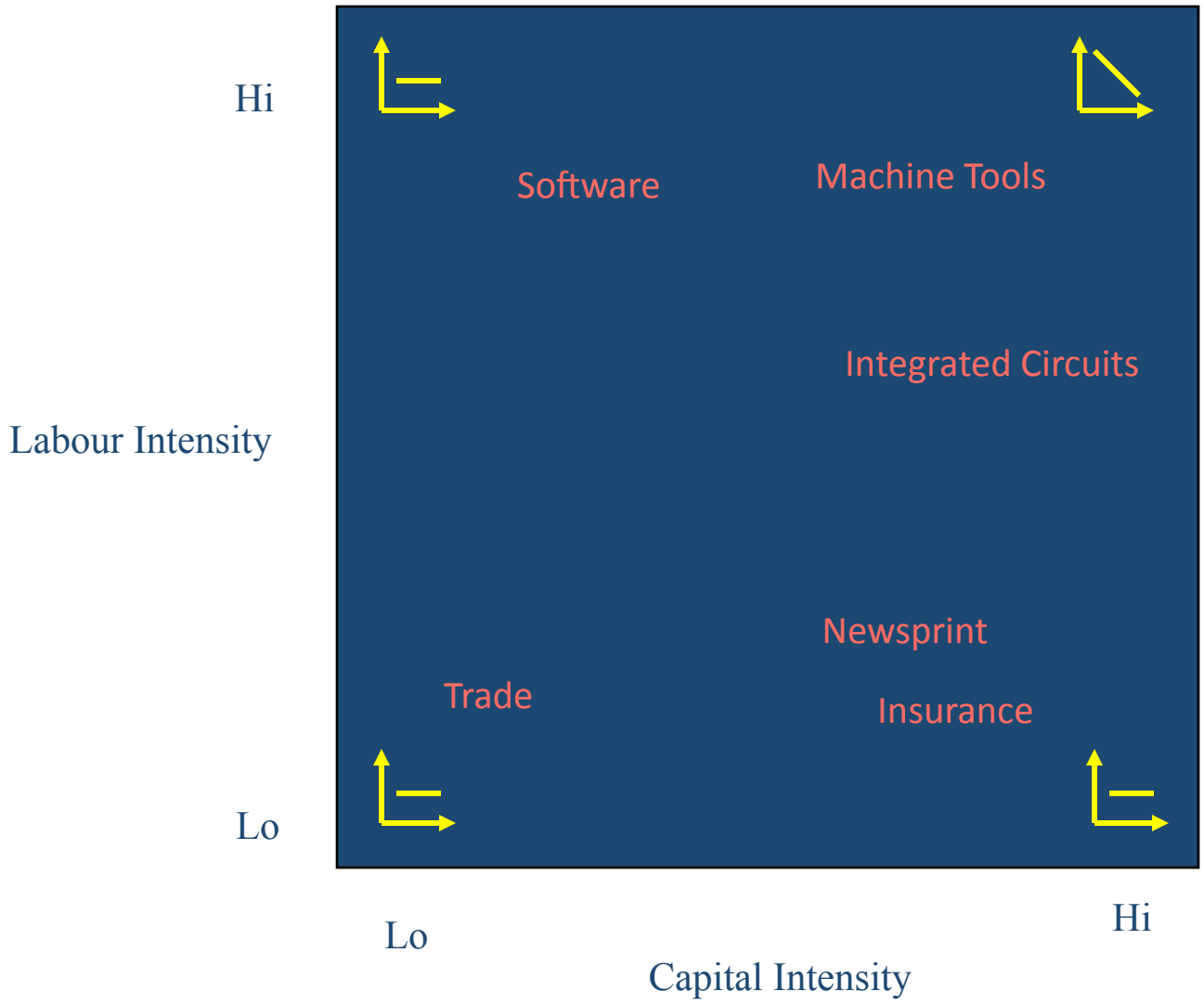


Bending the e-curve (2)

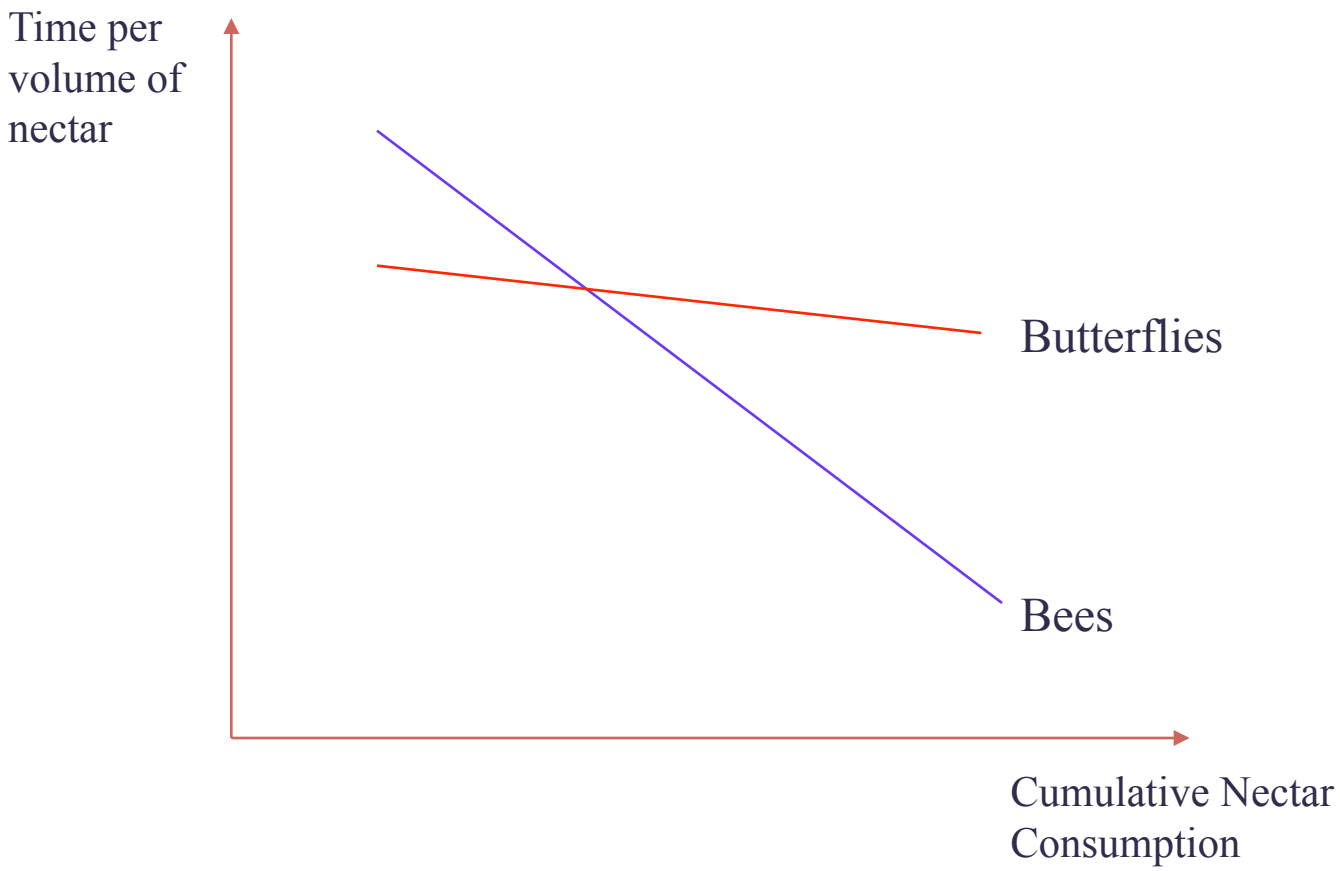
Reason 2: strategy and stealth



Driven by industry characteristics?



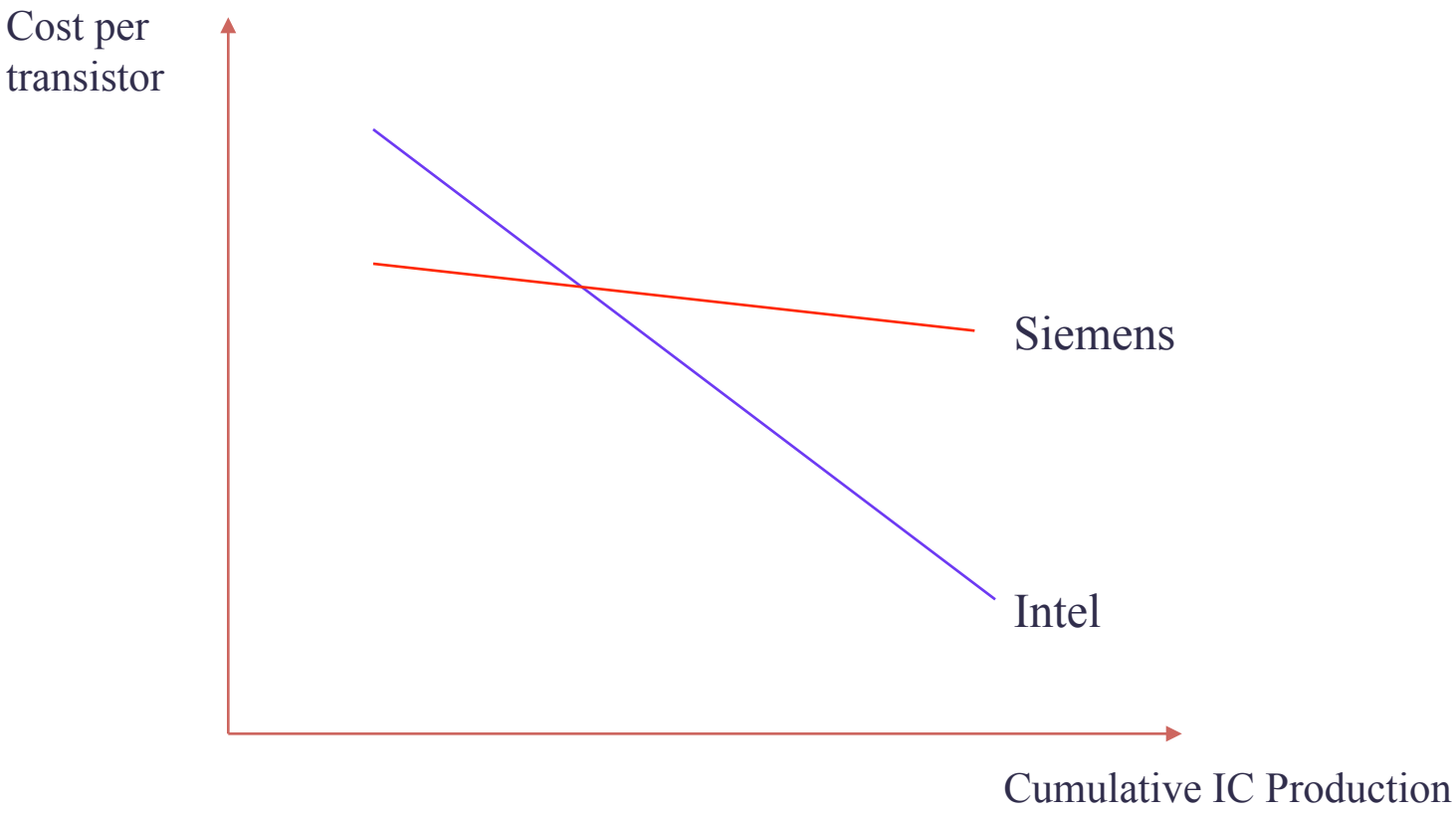
Hymenopterists vs. Lepidopterists



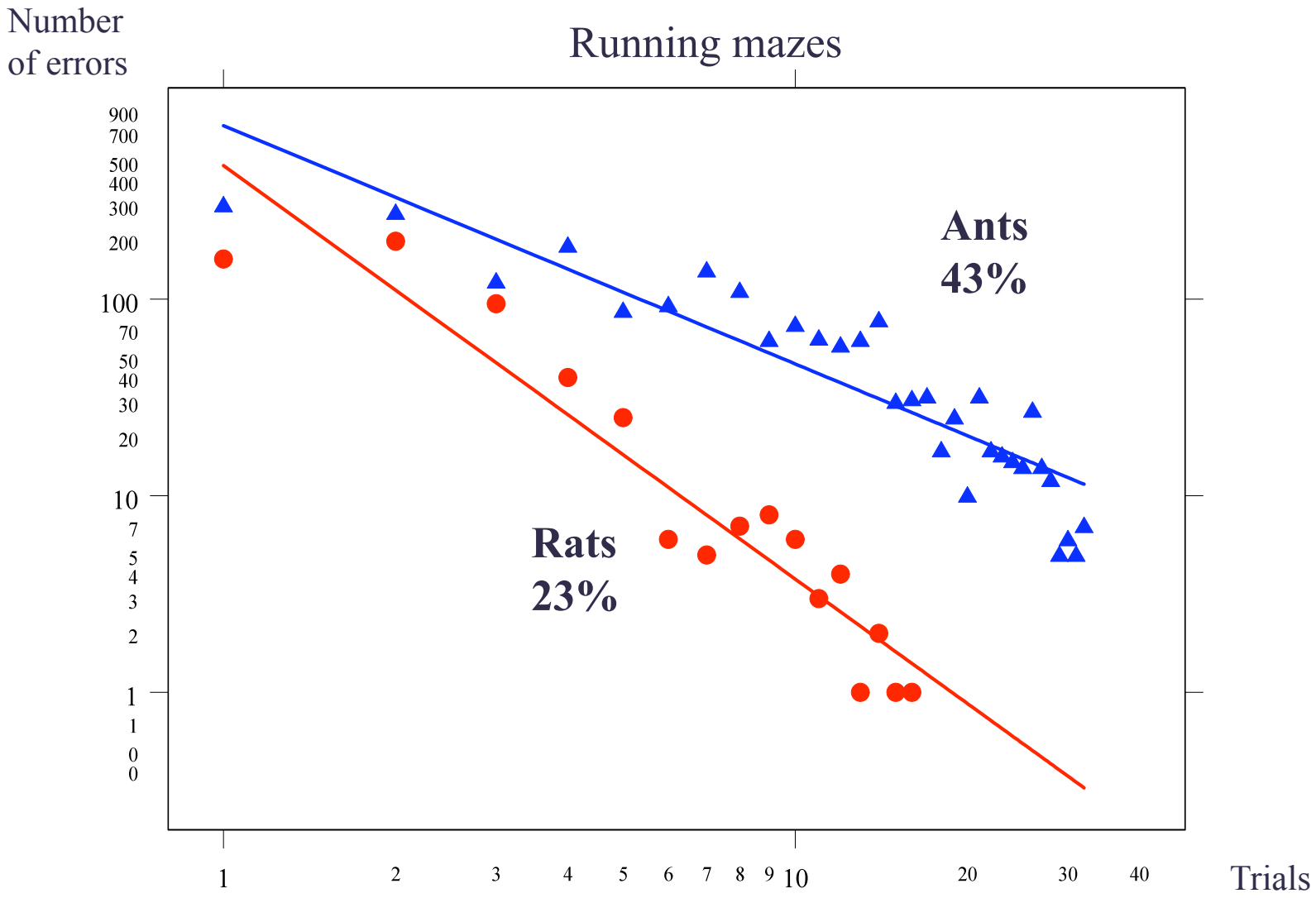
Science News, April 11, 1998 – *How Bright Is a Butterfly?*
By Susan Milius; Research: Dave Goulson and J.S. Cory; University of Southampton (UK)

Integrated Circuits: Intel vs. Siemens

Competing on slope or volume?

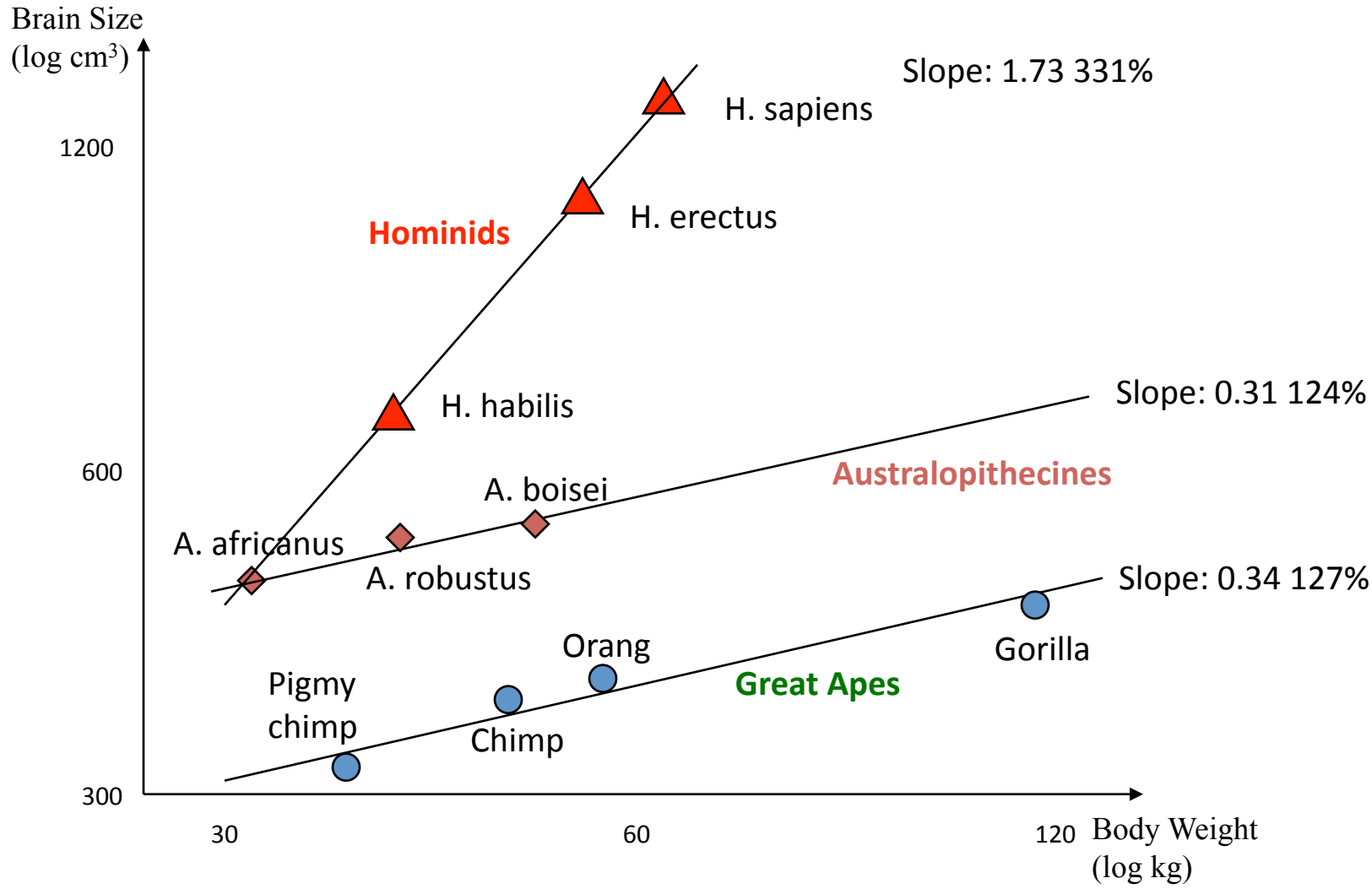


Culture vs. Organization



Attributed to T. Schneirla (1953) and E. O. Wilson (1971) in John T. Bonner: The evolution of culture in animals (1980)

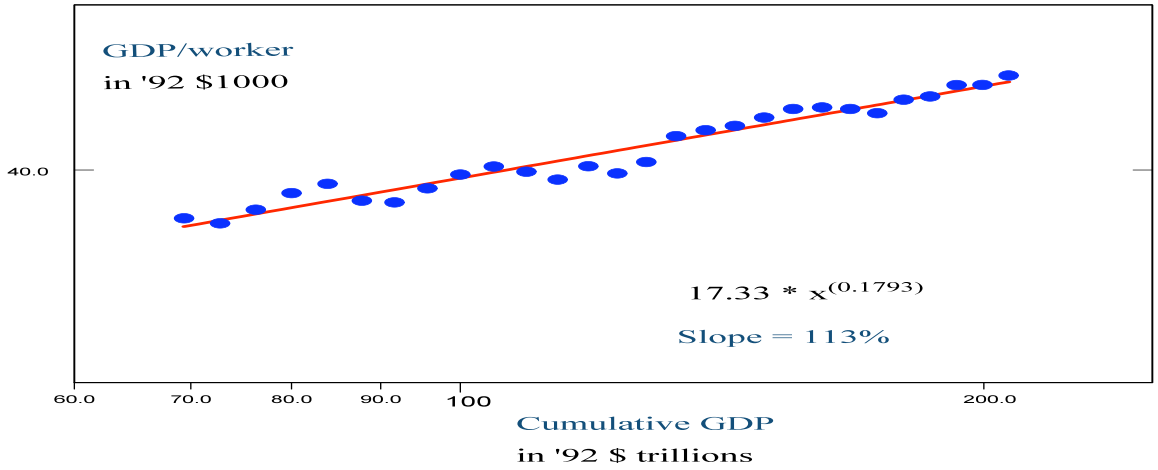
Slope Change in Brain – Body Allometry



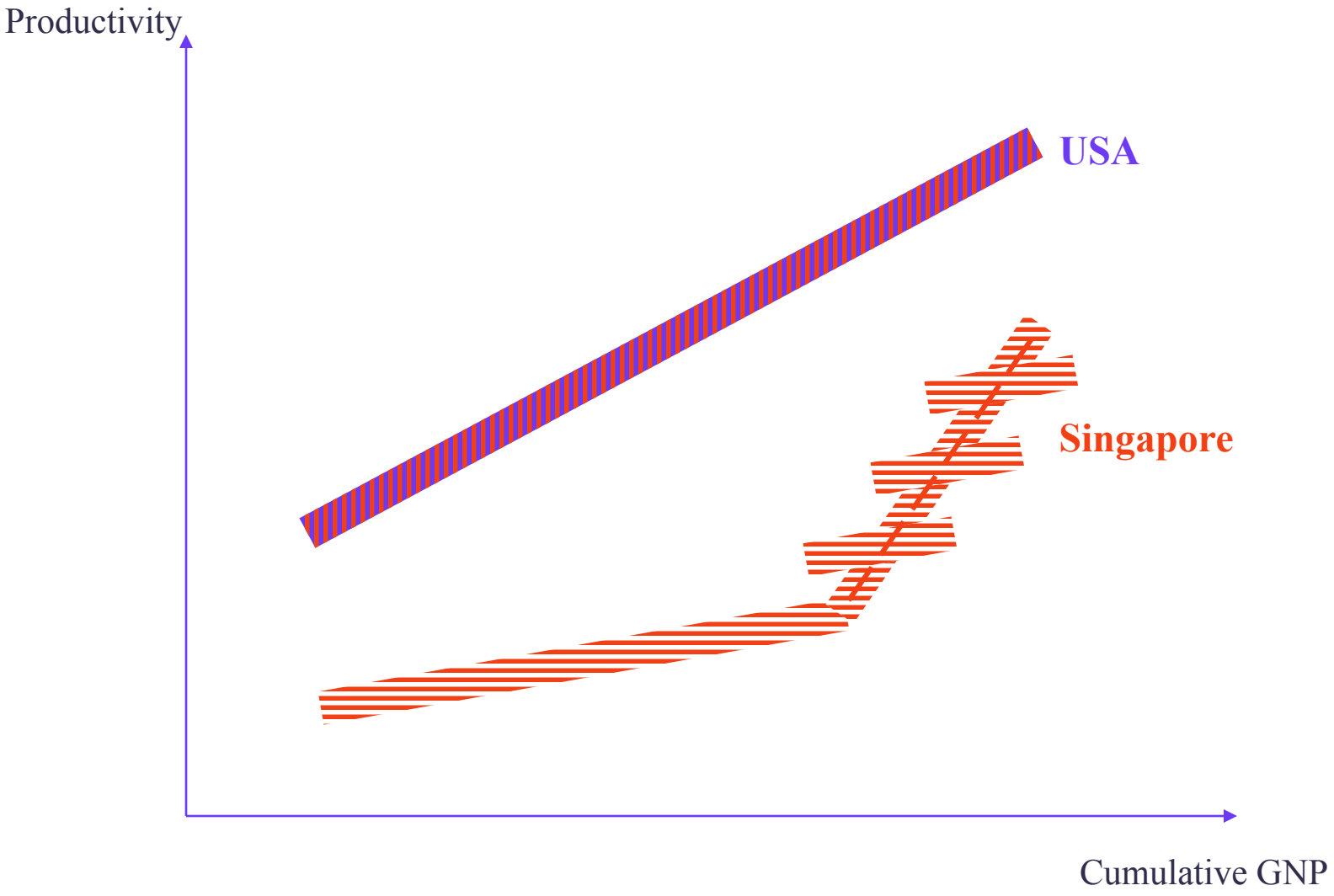
D. Pilbeam and S.J. Gould (Science 1974): Size and scaling in human evolution.

The Learning Curve of a Nation

US 1969 - 1996

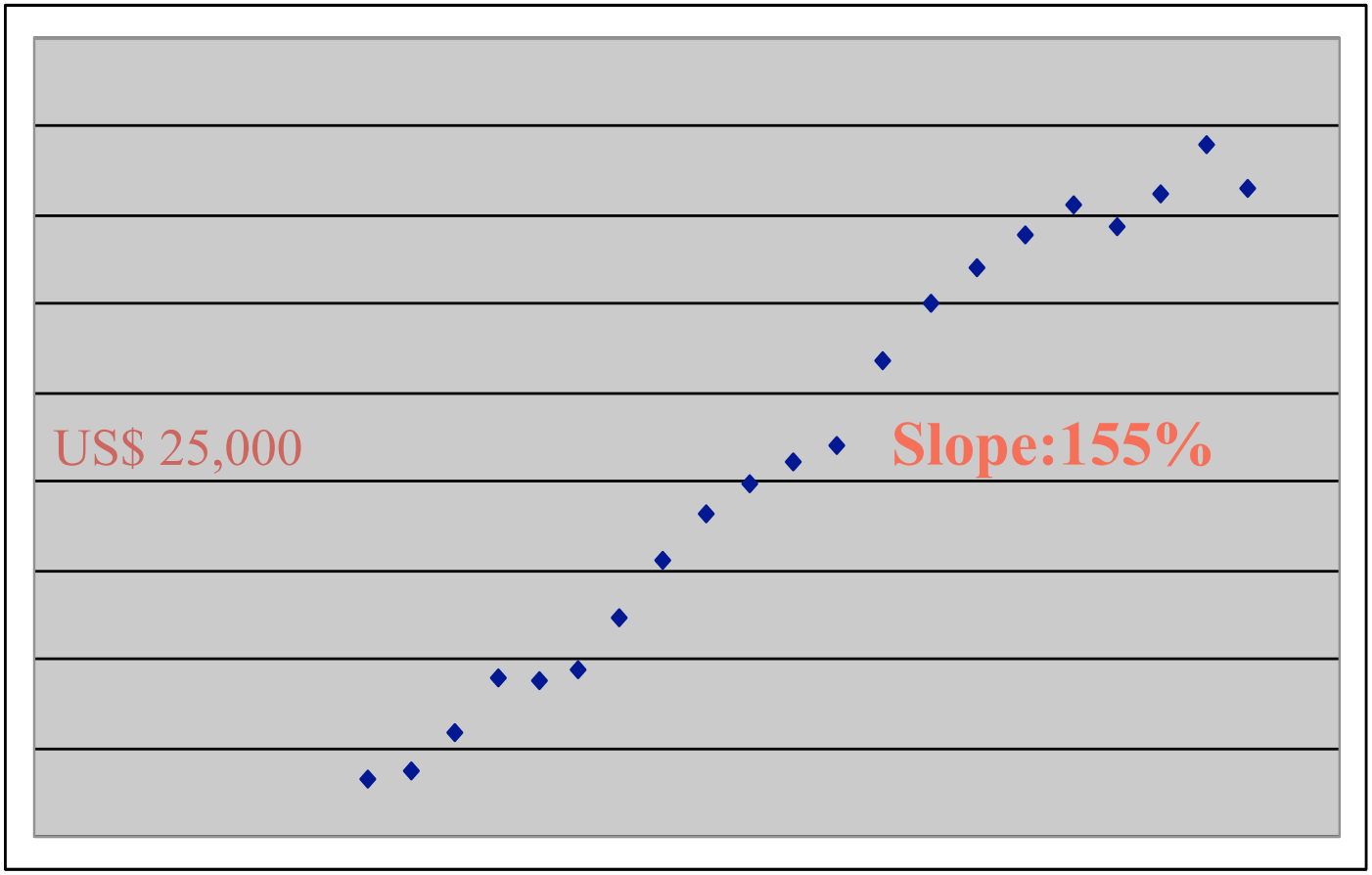


Singapore Quandary

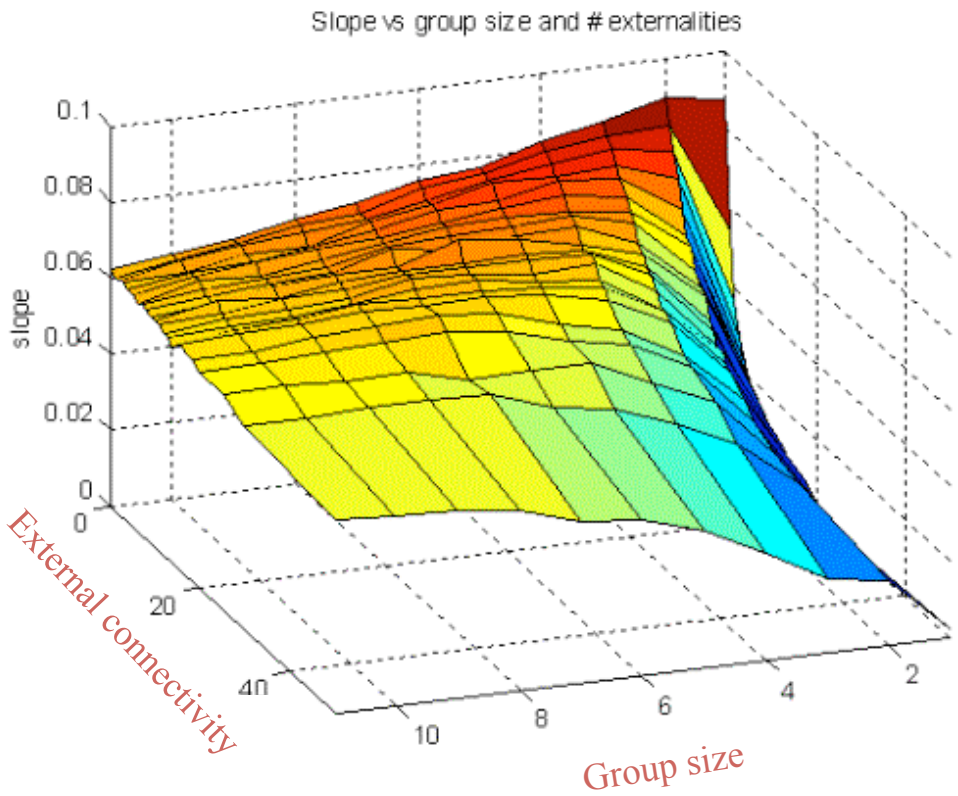


Leap-frogging: for how long?

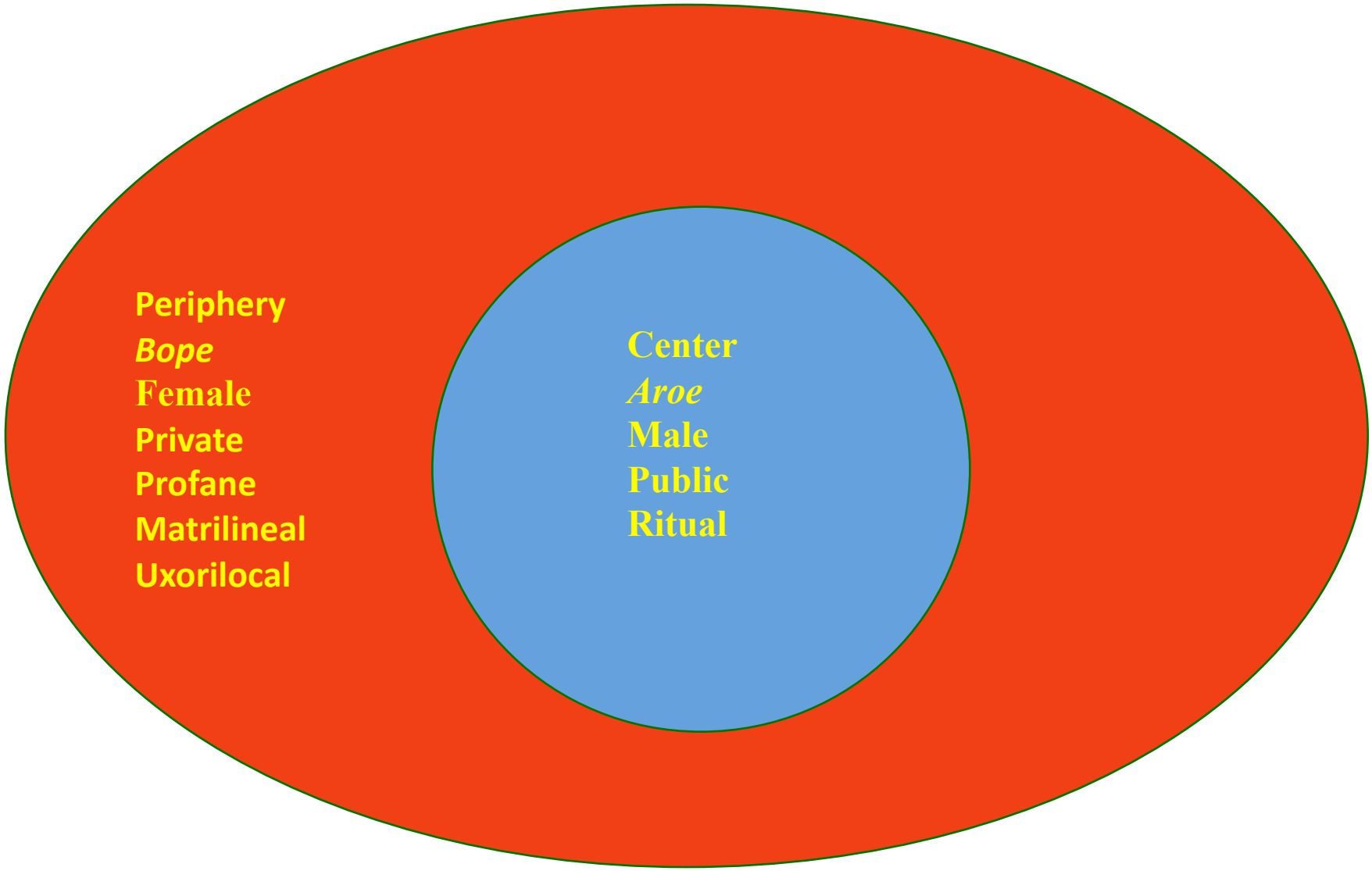
Singapore 1981-2001



Social Structure and Learning



The Bororo Village

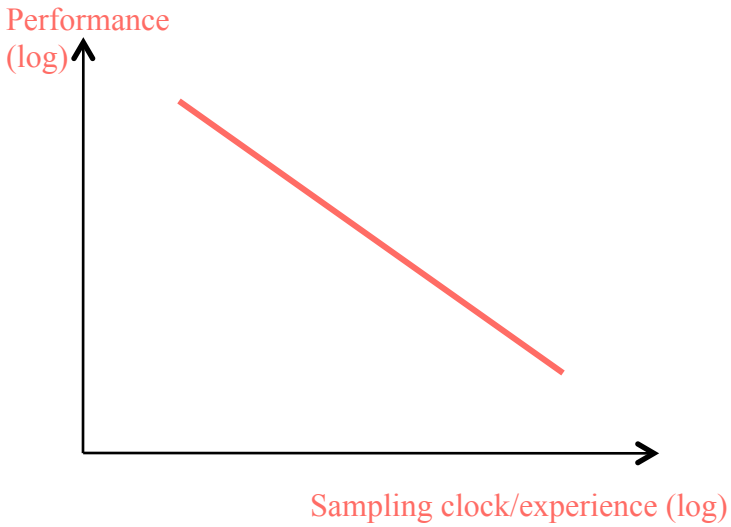


J. Christopher Crocker – *Vital Souls*

Learning the Basics of Learning

CSSS 2008 Project

Model of a basic learning "monad" (a *lonad* or a *loid* from a *learning somethingoid*):



Cumulative sampling	⟷	Specific action
Estimate (compression)	⟷	Template, routine,…
Estimators	⟷	Learning methods
Distributions	⟷	Environments
Location	⟷	Optimum
Loss function	⟷	Cost disadvantage

With:

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David Papo
Technion—Israel Institute of Technology

Prevailing Models Problematic

A look at three influential models:

- Muth (1986): “bag” of solutions, random search;
- Auerswald, e.a. (2000): graph of solutions, proximity search;
- Huberman (2001): pathways of solutions, “bag” of new edges.

Petitio principii in all (least in Huberman) by assuming “remarkable foresight” in telling good solutions from bad ones and to wait until former pop up:

- learning is explained by recourse to knowledge whose source is left unexplained.

Modest explanatory punch: variety of slopes remains elusive.

Relatively complex models and limited generality.

Estimation of Center of Normal Distribution with L_∞ Norm

```
LearnBasic [redacted]alDistribution [redacted] 1 [redacted]
 MidRange, SqErr, 128, 1000 [redacted]
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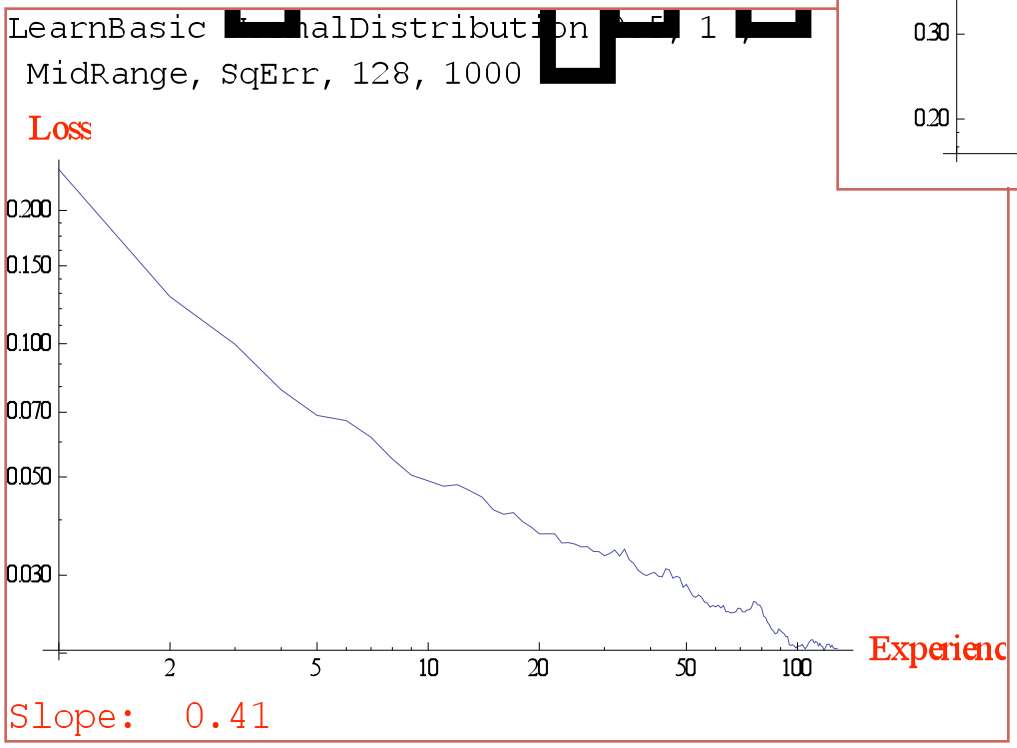


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Slope:  0.41
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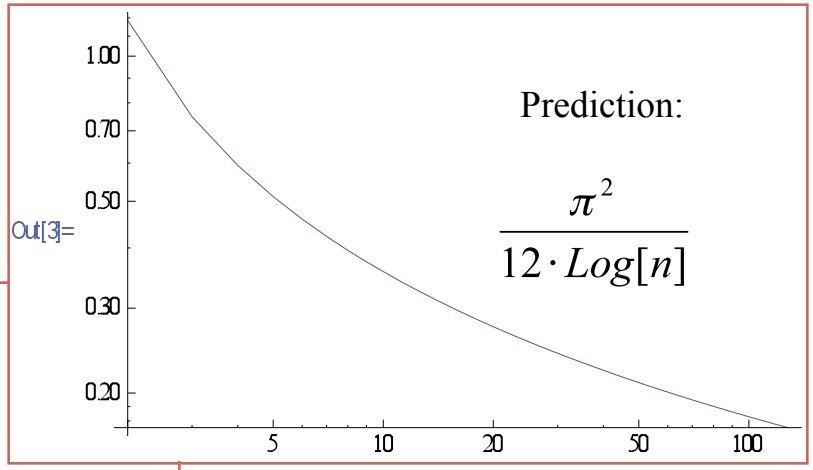
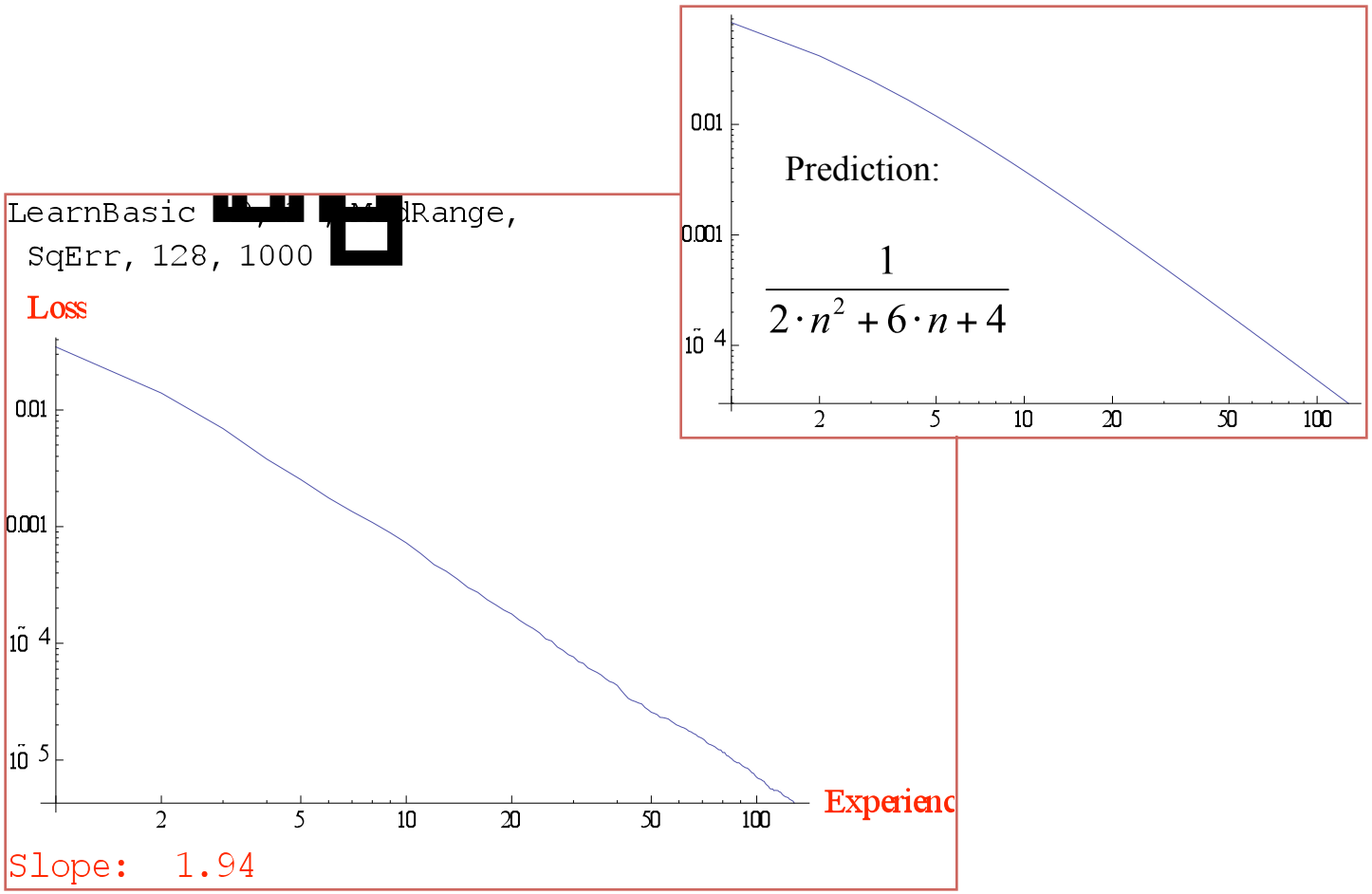
Out[3]=

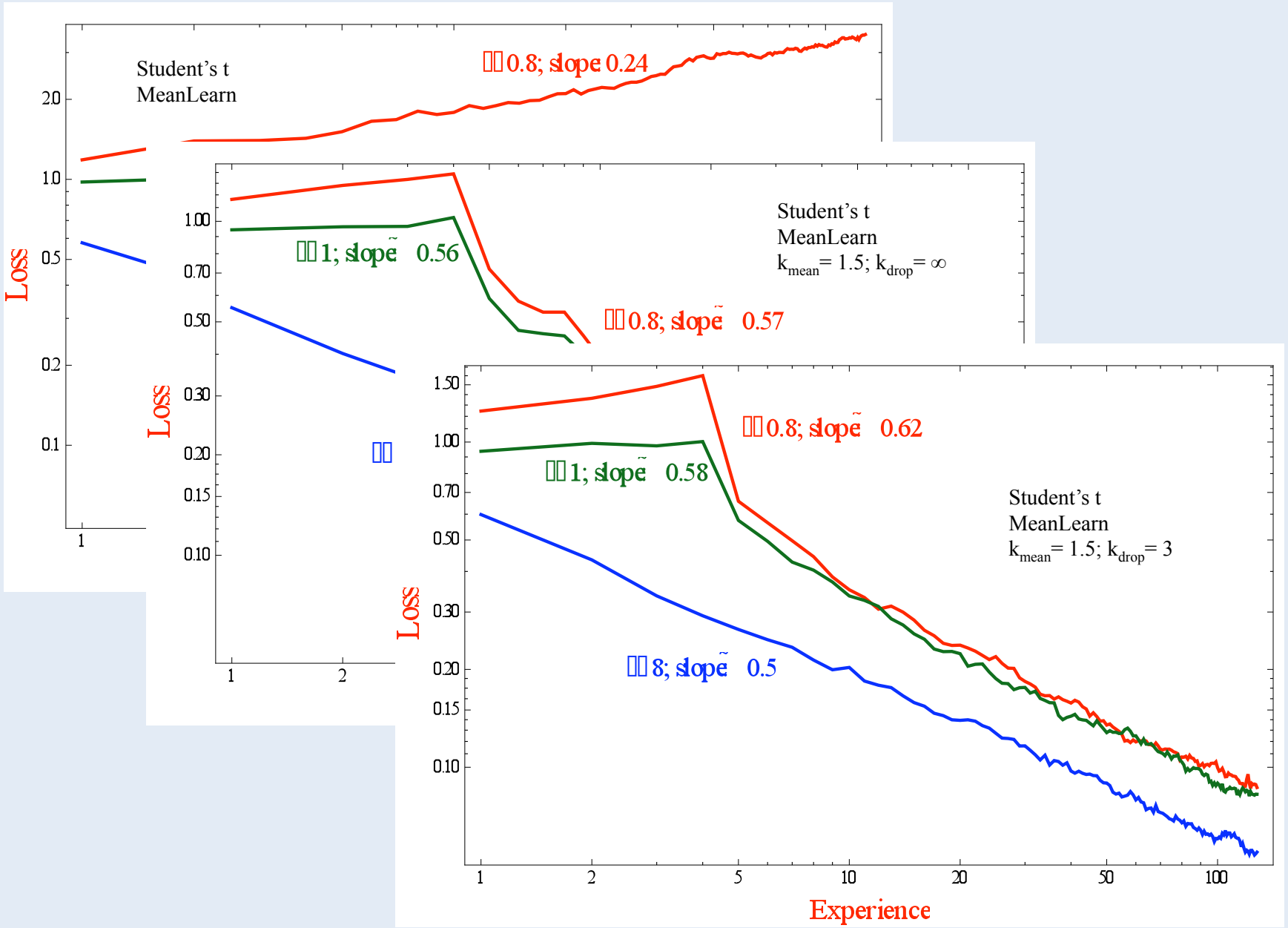


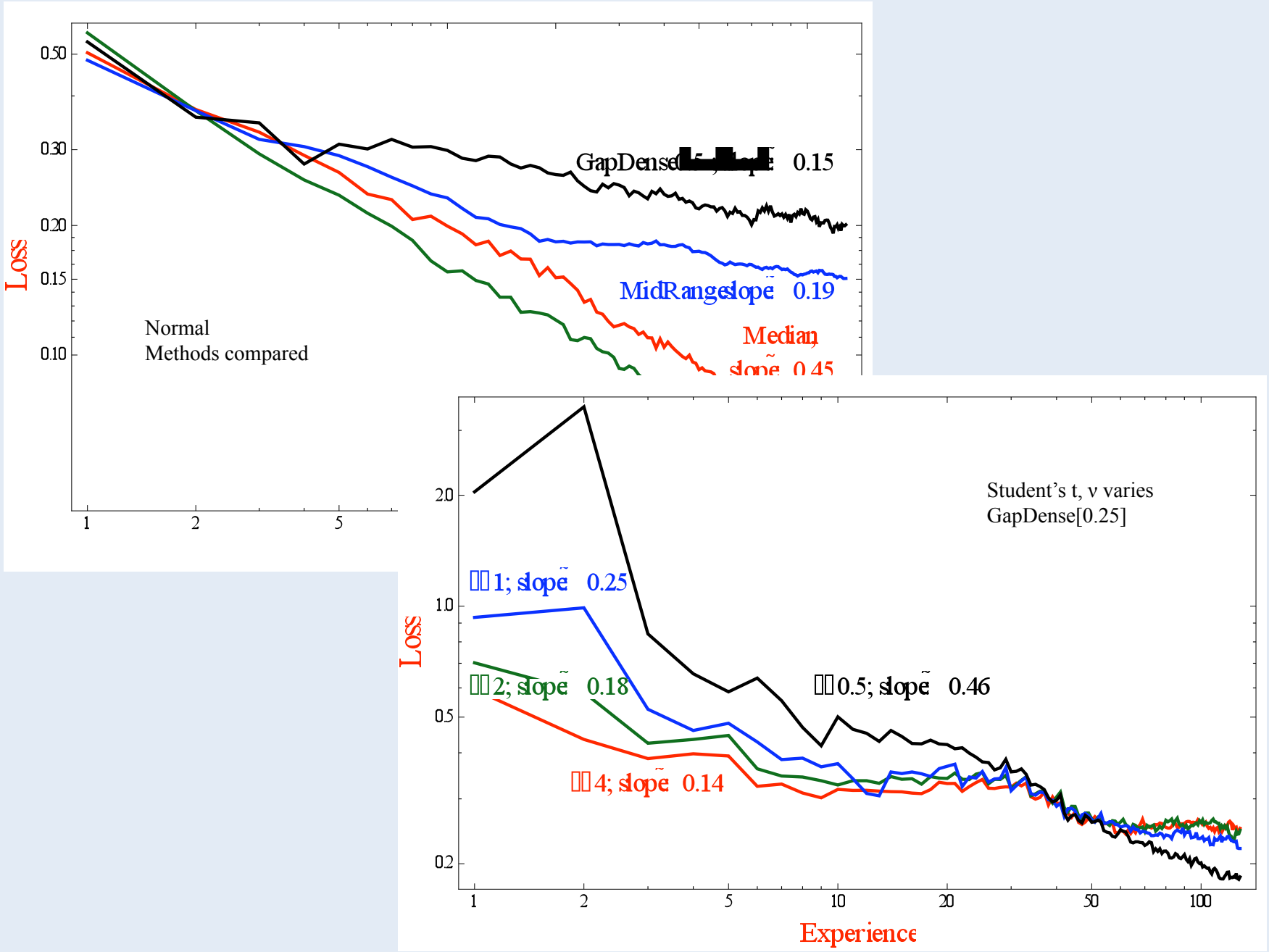
Prediction:

$$\frac{\pi^2}{12 \cdot Log[n]}$$

Estimation of Center of Uniform Distribution with L_∞ Norm



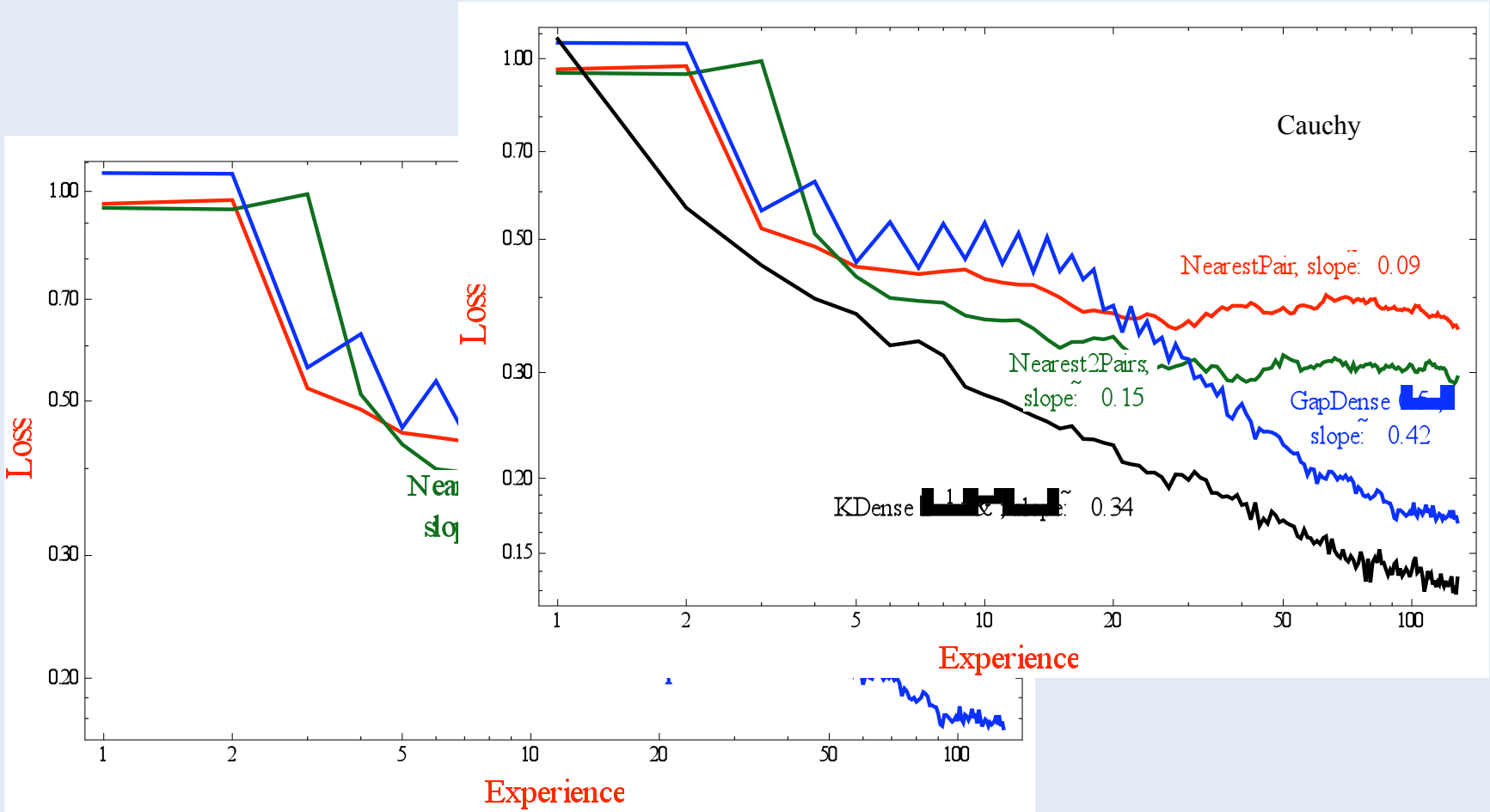

Student's t
MeanLearn
0.8; slope 0.24
Loss
Student's t
MeanLearn
k_mean= 1.5; k_drop= ∞
1; slope ~ 0.56
0.8; slope ~ 0.57
Loss
Student's t
MeanLearn
k_mean= 1.5; k_drop= 3
0.8; slope ~ 0.62
1; slope ~ 0.58
8; slope ~ 0.5
Loss
Experience


Loss
0.50
0.30
0.20
0.15
0.10
1
2
5
GapDense
0.15
MidRange
0.19
Median
0.45
Normal
Methods compared
Loss
2.0
1.0
0.5
0.2
1
2
5
10
20
50
100
Experience
Student's t, ν varies
GapDense[0.25]
1; slope 0.25
2; slope 0.18
0.5; slope 0.46
4; slope 0.14

Proper Breeding

The "neglected" estimator (mode, density):

- Grenander/Parzen too "otherworldly;"
- but of evolutionary interest:
  - multiple sensory (micro-)receptors;
  - benefits in seeking out abundance and avoiding scarcity.



The principal merits of this model in our view are:

- A natural mapping between model and a variety of learning phenomena.
- Capable of generating a wide variety of slopes and of trace this variation to what is essentially an ecological (mis)match between environment and learning method.
- Learning methods can evolve and hybridize in simple gradual steps:
  - improved the rate of learning (slope) in a particular environment and/or
  - gain in robustness across different or varying environments.
- "Atomic:" single-agent of minimal complexity. Structured (spatial, social) ensembles of multiple agents with feed-back and feed-forward mechanisms are easily conceived and readily justified in several contexts (neuronal configurations, social organizations, &c.).
- Parsimony and explanatory punch. No recourse to some prior and unexplained source of foresight and prudent judgment in avoiding "bad ideas."

Theory
Suite of "learning" metaphors
Modeling

Δ slope