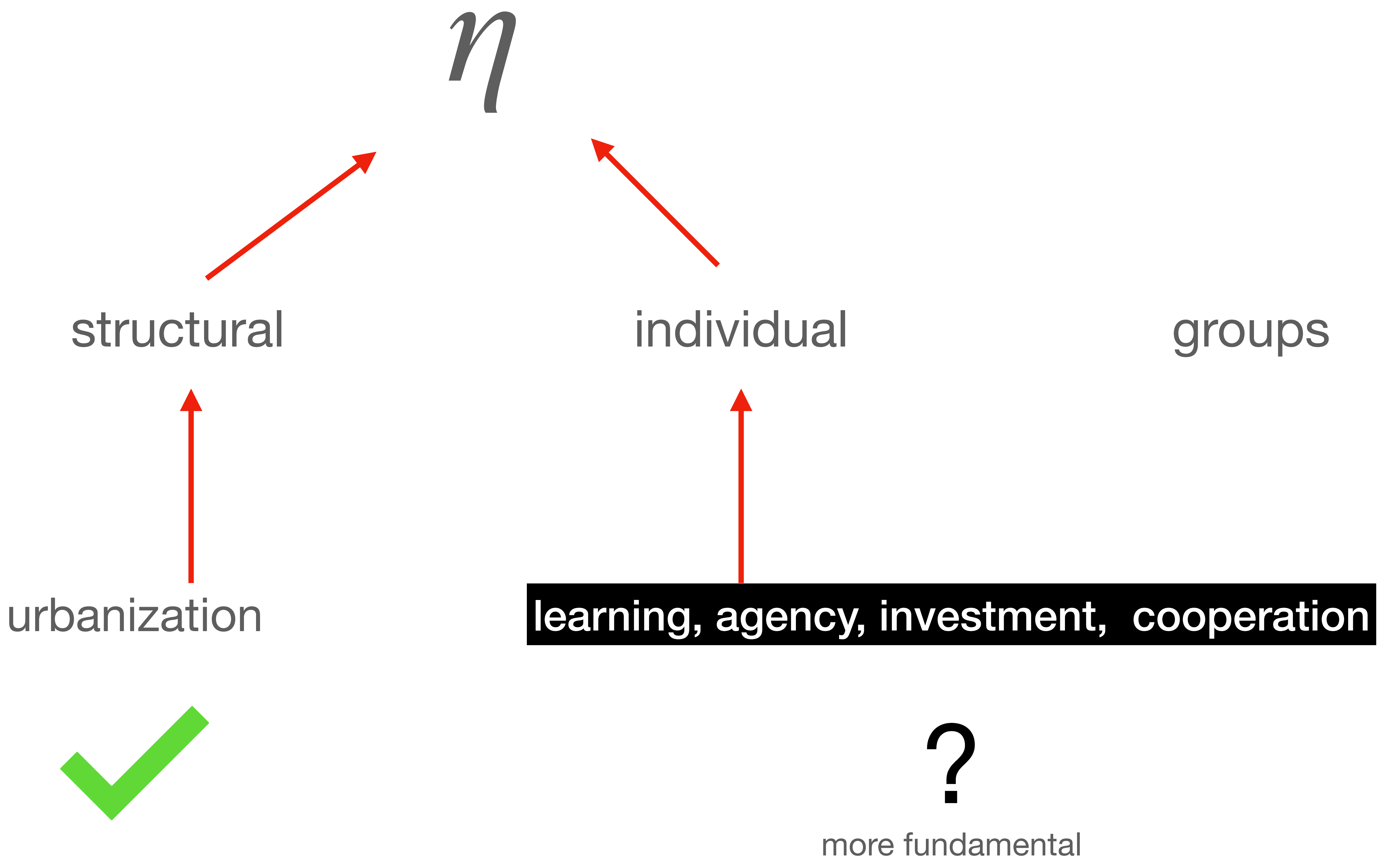
Lecture 17

Economic Growth, Information and Cities

17.1 Information and Economic Growth: Fortune's formula and beyond IUS 9.3

What creates growth?



From an individual's perspective:

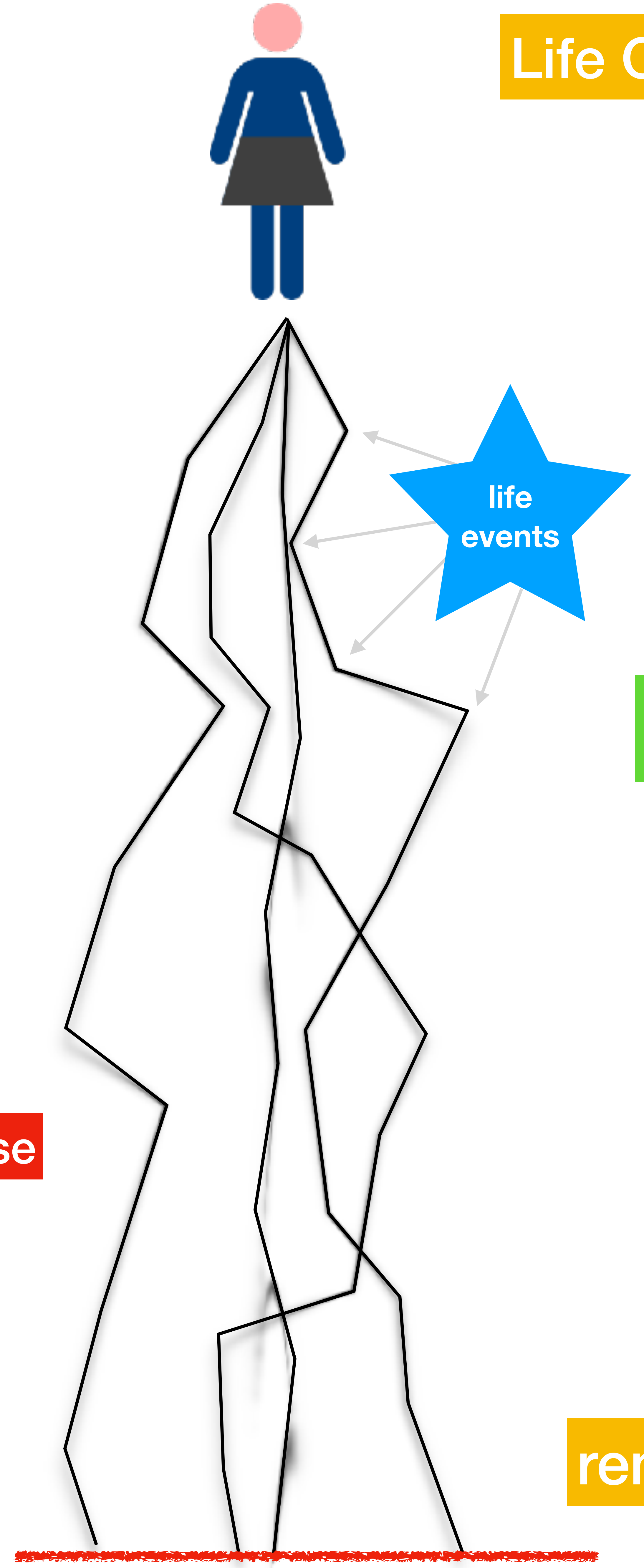
Life Course

labor and capital; time and energy

What to "invest" effort in?
uncertainty & risk
short-time vs long-term decisions
peer group and 'culture', innovation

Changes when people come to cities

time



agency + "environment"

Changes through the life course

cumulative (dis)advantage
intervention points
knowledge and productivity
bad luck and vicious cycles

remember: your life path [world line]

outcomes

how to invest time and effort, resources?

There is a deep and beautiful relationship between

Prediction

Resources

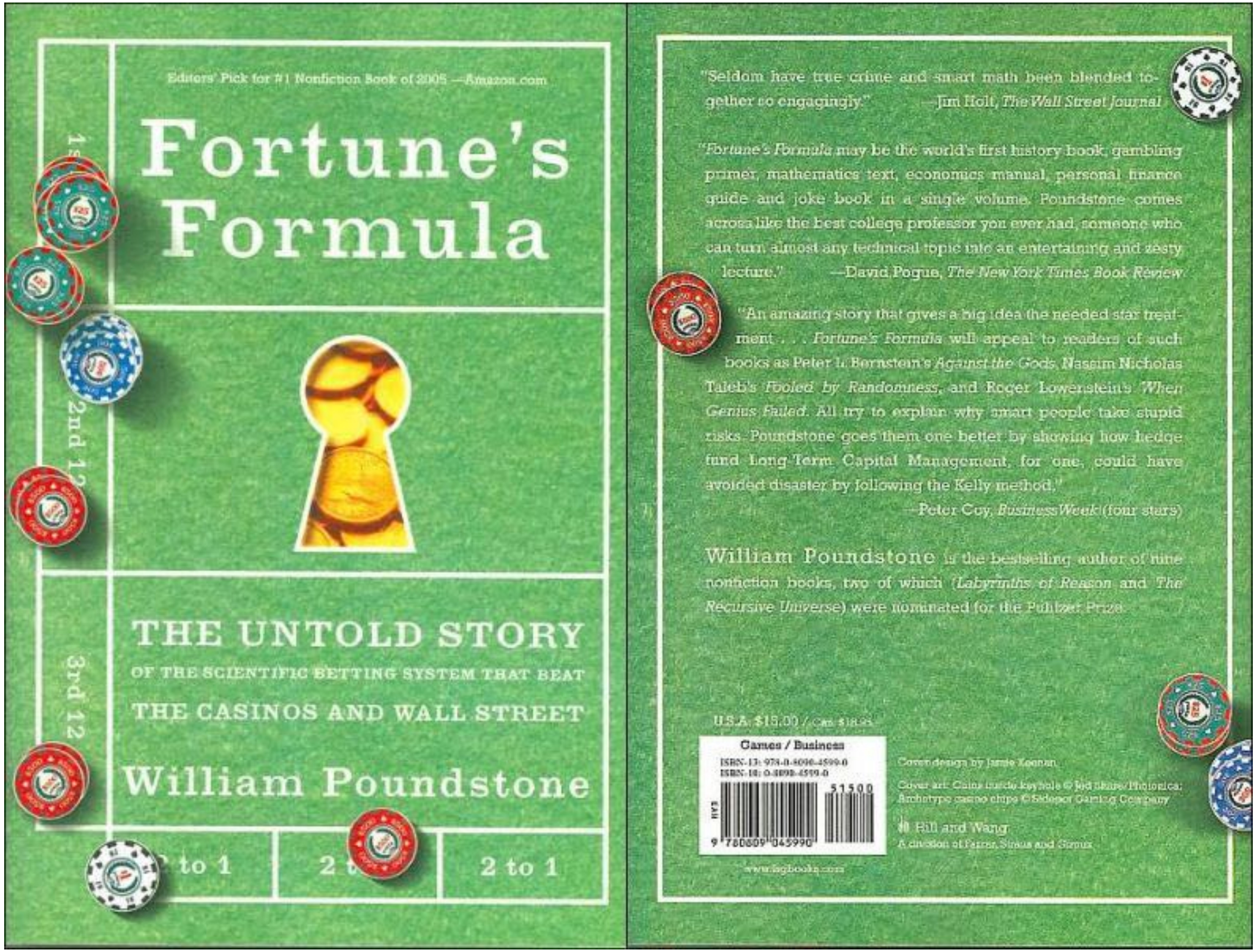
“Knowledge”

“Wealth”

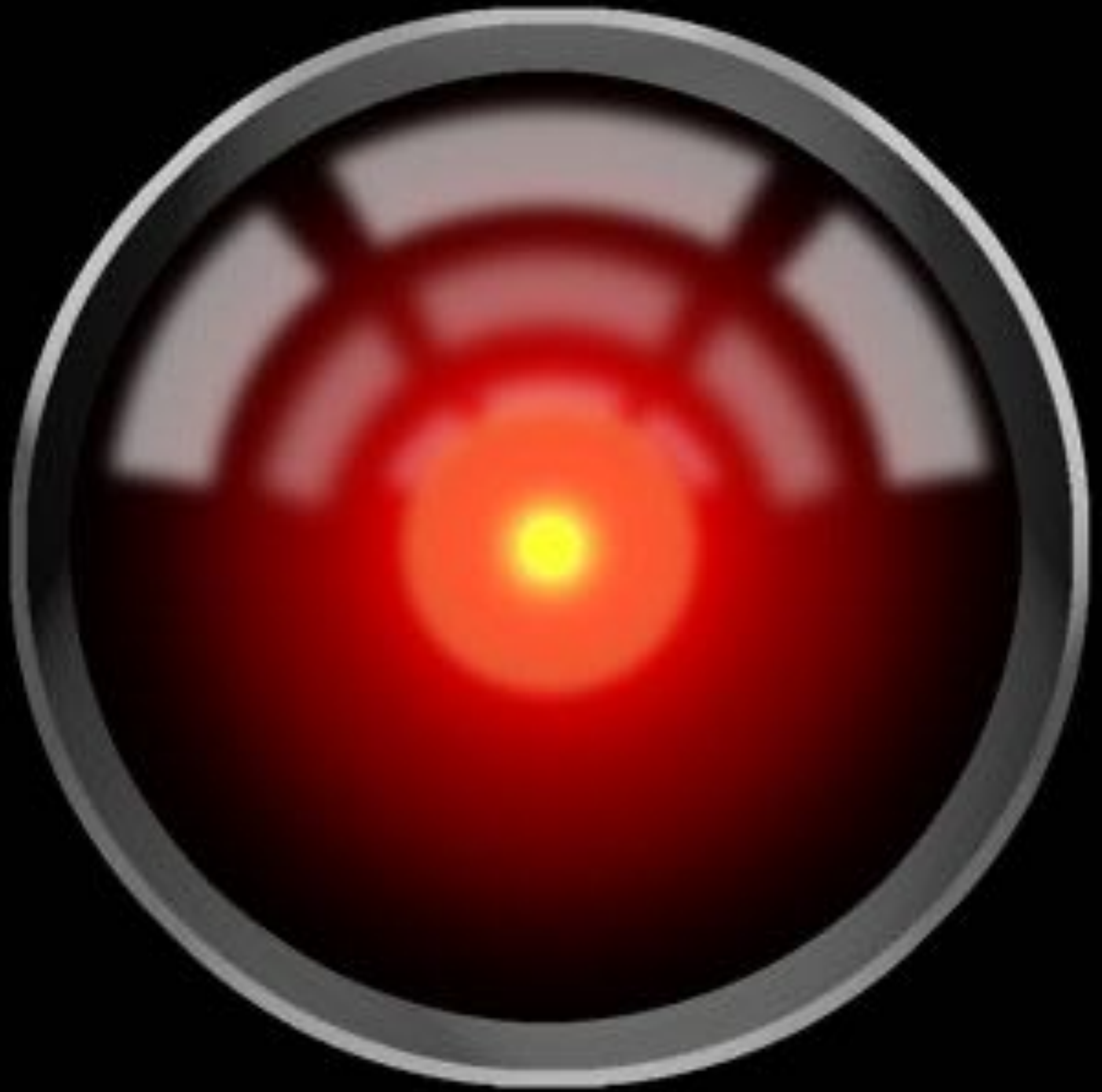
In finance, economics

This is common across all complex systems. Unifies evolution, (machine) learning theory, financial mathematics.

There is an optimal way to approach this problem…



http://www.fortunesformula.com



betting on horse races

with math!

A New Interpretation of Information Rate

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By J. L. KELLY, JR.

(Manuscript received March 21, 1956)

If the input symbols to a communication channel represent the outcomes of a chance event on which bets are available at odds consistent with their probabilities (i.e., "fair" odds), a gambler can use the knowledge given him by the received symbols to cause his money to grow exponentially. The maximum exponential rate of growth of the gambler's capital is equal to the rate of transmission of information over the channel. This result is generalized to include the case of arbitrary odds.

Thus we find a situation in which the transmission rate is significant even though no coding is contemplated. Previously this quantity was given significance only by a theorem of Shannon's which asserted that, with suitable encoding, binary digits could be transmitted over the channel at this rate with an arbitrarily small probability of error.

https://www.princeton.edu/~wbialek/rome/refs/kelly_56.pdf

An illustration:

Simplest case: binary choice   heads/tails, red/black, 0/1 etc

Consider a series of events: $e_1, e_2, \ldots, e_i, \ldots \in E$ Environment

Payoff of guessing right: $o(e_i) \geq 1.$

Your knowledge: **(intuition, friend, experience):** $s_1, s_2, \ldots, s_i, \ldots \in S$

0 0 1 1 0 0 1 1 0 1

Given your knowledge, allocate: $f(e \,|\, s) r$ $\sum_e f(e \,|\, s) = 1$

fraction of your “wealth”

At each step the environment returns state e_i

Your resources (wealth) grow like: $r \rightarrow r' = o(e_i) f(e_i \,|\, s_j) r$ proportional to r

After n steps:

$$r(n) = \Pi_{j=1}^{n} o(e^j) f(e^j) r$$

product: choices compound (multiplicatively)

The *average growth* rate is then

$$v = n/T$$

velocity of investments

$$\eta = \lim_{n\to\infty} \frac{v}{n} \ln \frac{r(n)}{r} = v \sum_{i=1}^{E} P(e_i) \ln o(e_i) f(e_i) \,.$$

probability of e_i

$$\nu = \frac{n}{t}$$

speed of investments

What is the best allocation?

maximizes growth rate, subject to normalization

$$F[f] = \eta[f] + \lambda(\sum_{e_i} f(e_i) - 1)$$

$$\frac{dF}{df} = 0 \rightarrow \frac{P(e_i)}{f(e_i)} - \lambda = 0 \rightarrow f(e_i) = \frac{P(e_i)}{\lambda} \,.$$

$$f(e_i) = P(e_i)$$

"proportional betting"

$$\eta = v(\overline{\ln o} - H(E))$$

$$\overline{\ln o} = \sum_{i=1}^{E} P(e_i) \ln o(e_i)$$

odds must be good enough

more complex environments are costly

What happens when resources are conserved across the population (equilibrium)?

Total money bet = Total money paid — Bookie

Total sales = Total purchases (demand) — Market

We can then calculate the odds (or prices):

Consider a population of agents j=1,…,N

Each invests their resources r_j, using an allocation $f_j(e_i)$

Total bet:

$$N\bar{r} = \sum_{i,j} f_j(e_i) r_j$$

Total paid:

$$\sum_j f_j(e_i) o(e_i) r_j = o(e_i) \sum_j f_j(e_i) r_j$$

$$o(e_i) = \frac{N\bar{r}}{\sum_j f_j(e_i) r_j} \rightarrow \frac{1}{P(e_i)}.$$

?

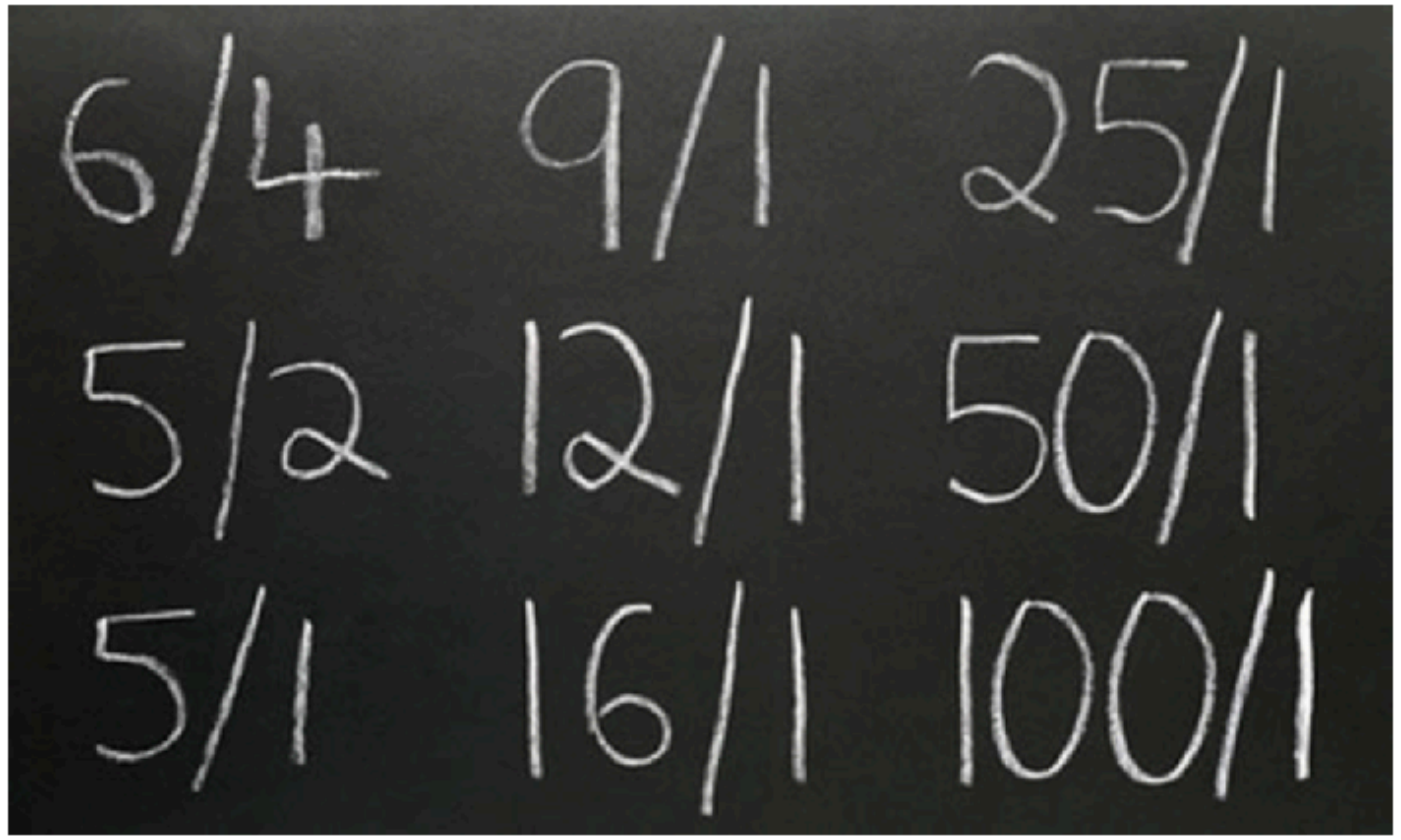
Note that: $\sum_j f_j(e_i) r_j = \sum_j P(e_i | j) P(j) r_j = N\bar{r} P(e_i) + N\bar{r}\, covar(f_j(e_i), \frac{r_j}{N\bar{r}})$

How To Make A Fair Odds Line

By Derek Simon

https://www.usracing.com/news/horse-betting-101/making-a-fair-odds-line

Note: I wrote the following article several years ago, but received a request to post it again. It pertains to making a fair odds line and includes a link to an Excel program that I created to aid in the process.



Recently, I've been getting quite a few inquiries about fair odds lines — mainly, how does a horseplayer go about making one and what are they good for?

Let's kick off the discussion with the last question — after all, what's the use in creating something without first knowing what it does (trust me, I've seen enough science fiction movies to know this is a terrible idea)? Simply put, a fair odds line provides gamblers with a means of making rational wagering decisions.

For example, most players know that betting to win on a horse that is 2-5 or less doesn't make a lot of sense. To make any money on such steeds, a gambler would need to cash at least 71 percent of the time, which is extremely unlikely (not to mention the fact that the place and show payoffs would probably be just as high if not higher than the win return, making a win bet look that much more foolish).

https://www.usracing.com/news/horse-betting-101/making-fair-odds-line

Fair odds:

$$o(e_i) = 1/P(e_i)$$

Also average "belief"

$$\overline{\ln o} = \sum_{i=1}^{E} P(e_i) \ln o(e_i) \to H(E)$$

For fair odds, the growth rate vanishes:

$$\eta = v(\overline{\ln o} - H(E)) \to 0.$$

Because all agents are doing the same optimal thing, and resources are fixed

This reflects a situation when the agent does not have *inside* information

Need "better" knowledge to beat odds or "market" (average belief)

This is the basic argument for economic markets; not (fully) planned economies

Hayek 1945

https://www.jstor.org/stable/1809376

First, let's generalize the simplest situation:

$$o(e_i) = 1/P_m(e_i)$$ **guess (estimation) from market, or "crowd", or bookie**

Imperfect estimate

(simplify: $v = 1$)

$$\eta = \sum_{i=1}^{E} P(e_i) \ln \frac{f(e_i)}{P(e_i)} \frac{P(e_i)}{P_m(e_i)} = D_{KL}(P||P_m) - D_{KL}(P||f)$$

A better predictor than average grows !

can benefit from imperfect "markets" if we know the actual probability (better)

But what if we had special private information (edge)?

$$\eta = \sum_{i,j} P(e_i, s_j) \ln o(e_i) f(e_i | s_j)$$

"signal" = memory, knowledge, private channel

For optimal wealth generation:

Maximize

$$\eta = \sum_{i,j} P(e_i, s_j) \ln o(e_i) f(e_i \,|\, s_j)$$

to get the best allocation $f(e_i \,|\, s_j)$

This leads to

$$\boxed{f(e_i \,|\, s_j) = \frac{P(e_i, s_j)}{P(s_j)} = P(e_i \,|\, s_j)}$$

Fortune's Formula !!

conditional probability of specific event given private signal

$$\Delta\eta = \sum_{i,j} P(e_i, s_j) \ln \frac{P(e_i, s_j)}{P(e_i)P(s_j)} = i(E, S)$$

Mutual Information !!

between environment and private signal

improvement in rate from using the private signal

"knowledge pays"

https://www.sciencedirect.com/science/article/pii/S1631070519300350 resources will grow exponentially!!

with a rate given by the information of the signal on the environment

$$\Delta\eta = i(E,S) - D[P(e\,|\,s)\,||\,f(e\,|\,s)]$$

Either information is given ("friend")

> 0, if estimate is imperfect

Or it must be *learned*:

$$f(e\,|\,s^{n+1}) = \frac{p(e\,|\,s)}{p(e)} f(e\,|\,s^n)$$

Bayesian learning by observation/experience is Optimal

$$D[P(e\,|\,s)\,||\,f(e\,|\,s^n)] \sim 1/n$$

but learning from experience is VERY slow

No one learns what they know primality from experience, they learn most of it from others.

But observed growth rates are much smaller than in a game!

at the “frontier”

The meaning of an annual 2% growth rate:

1% = doubling (of capital) every 72 years

“rule of 72”

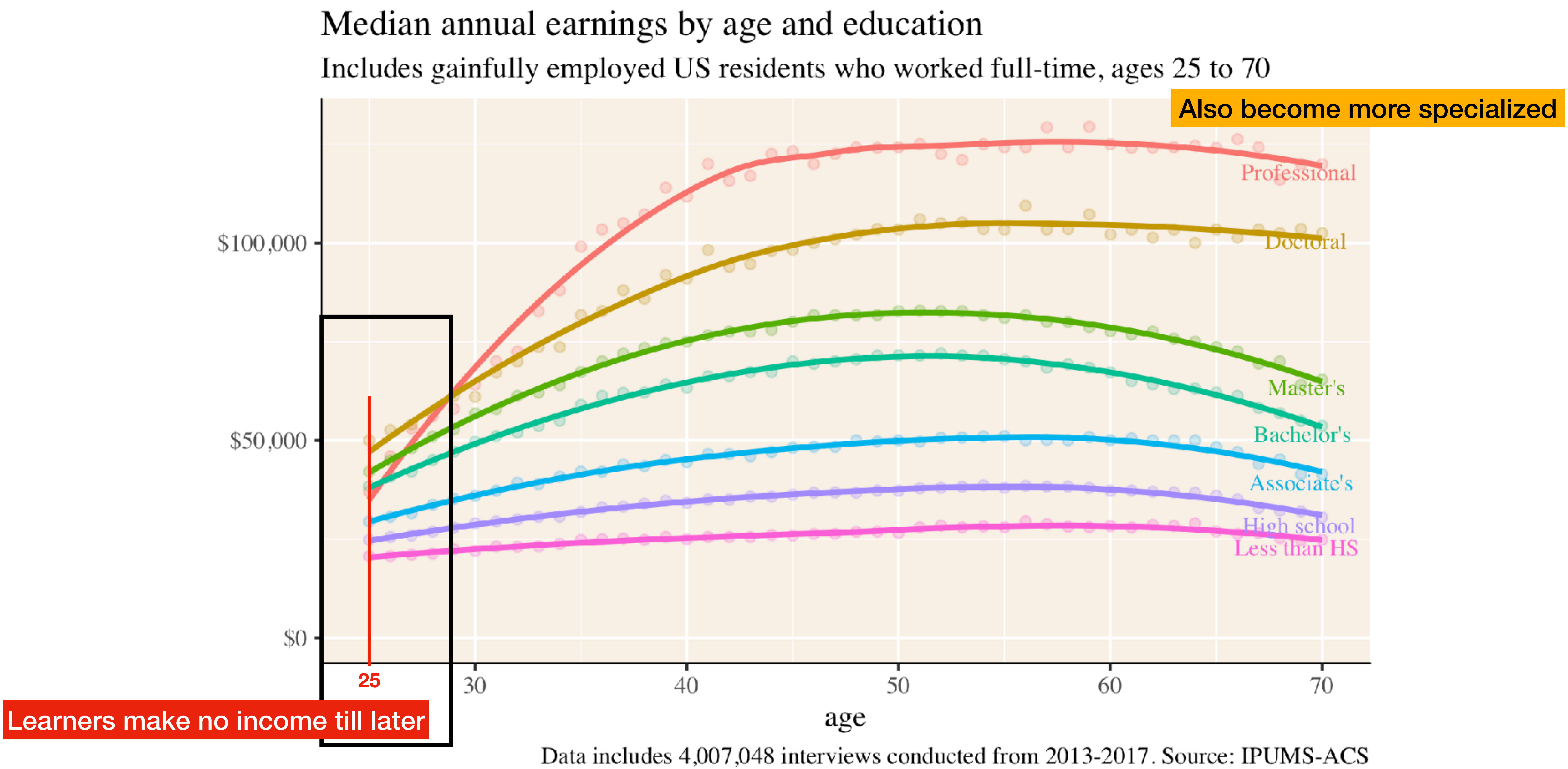
2% per year=doubling every 36 years

~ human generation

why so “slow”?

it takes a lifetime to create new productive information

opportunities that can be learned, education, training, predictability all matter a lot



Importance of life course + learning environments

https://johndjohnson.info/post/some-graphs-about-wages/

Making new (complex) things is very difficult for individuals as it requires integrating a lot of knowledge

Markets/bets/search engines only integrate information to a point : averaged between individuals

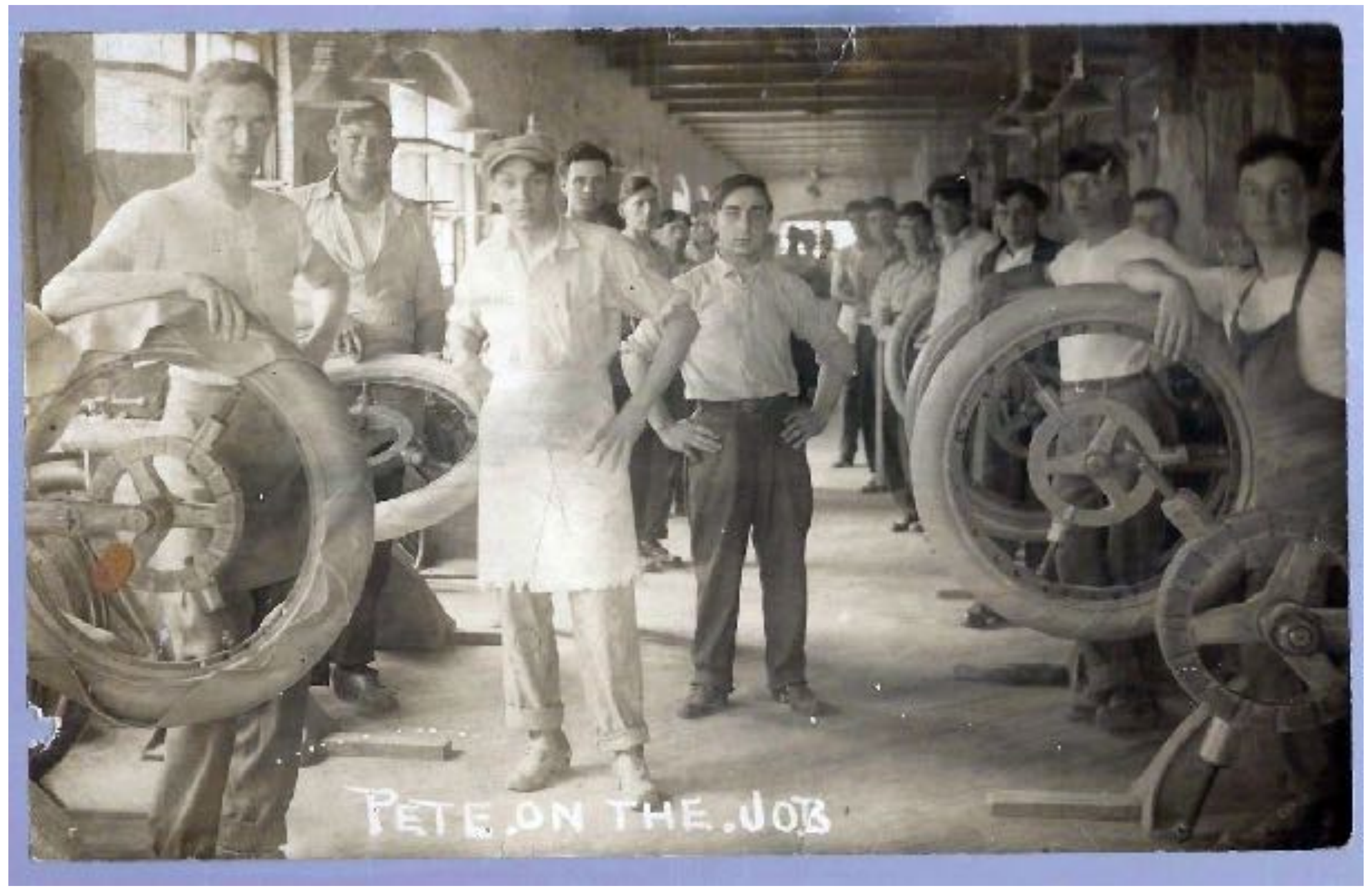
Additional assembly mechanisms are necessary

Firms, organizations, cities

Integration over time has a parallel in integration in socioeconomic networks (over space)

But whose knowledge (in the production of complex things)?

Whose Resources?



Making the Boeing 787 (“Dreamliner”)

The New York Times

Another Delivery Delay for Boeing’s Dreamliner

Share full article

Parts shortages and logistics problems have forced Boeing to postpone deliveries of its Dreamliner, a new wide-bodied 787.
Elaine Thompson/Associated Press

By Leslie Wayne
April 10, 2008

https://www.nytimes.com/2008/04/10/business/10boeing.html

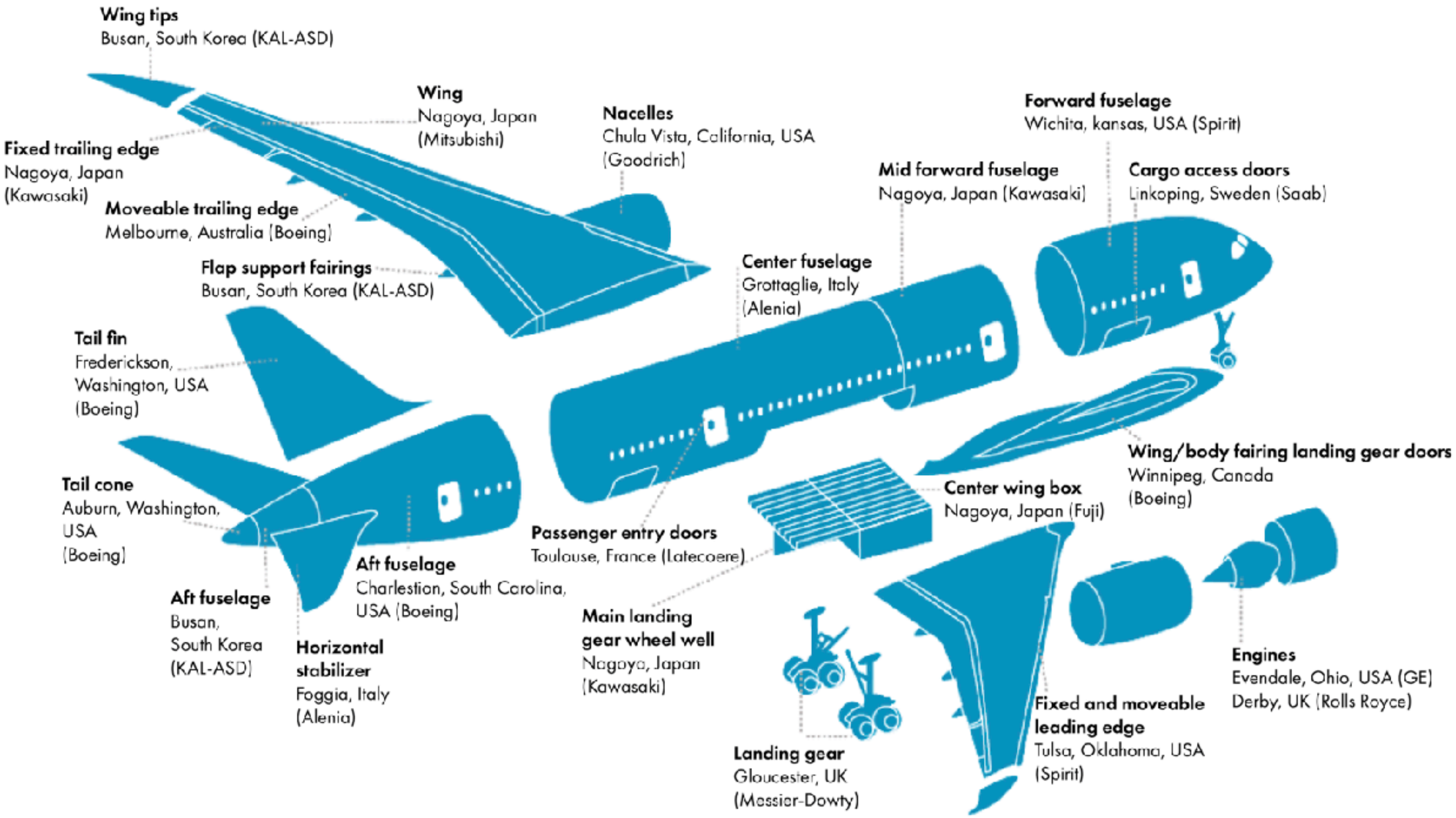
Turning to the World for the 787:

70% of manufacturing outsources

50 tier 1 partners / suppliers

135 manufacturing sites worldwide

4 continents



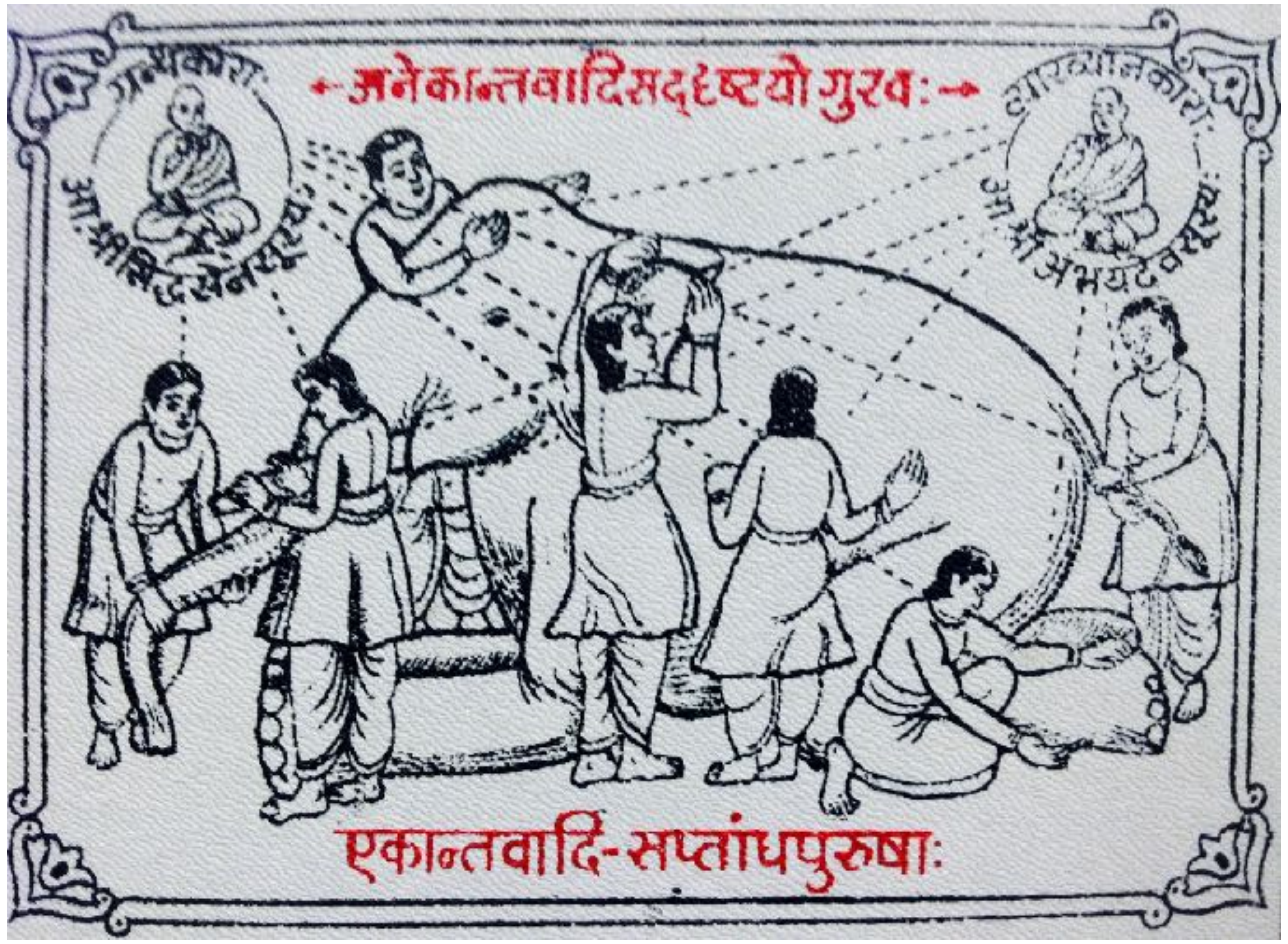
https://www.whitehorncapital.com/whitehorn-blog/outsourcing-the-dreamliner

Organizations have synergistic information

information in the organization is more than sum of the parts!

$$I(\{Y\};X) > \sum_j I(Y_j, X)$$

how should earned resources be distributed among agents?



Blind men and the elephant. credit: wikipedia

Team Production Problem

Division of knowledge and Labor:
and putting it back together fairly, so that it can be repeated and elaborated

https://onlinelibrary.wiley.com/doi/10.1111/j.1756-8765.2009.01047.x

Firms and Organizations

synergy and redundancy

1) Organizations have synergistic information

coordination of people's behavior towards a common goal = new information structures for task

2) Information can also be redundant

two people can know the same thing

3) Diversity of Information (maximal synergy) is necessary for growth:

maximum information requires "maximum synergy"=maximum "diversity" !

not for efficiency! not even for justice: For fastest *collective* growth and knowledge

Consequences:

- knowledge always wins over initial capital*

- knowledge has an enormous value, for others and into the future

positive externalities, spillovers

- knowledge producers are not able to capture its full value

public investment is necessary, “public goods problem”

- knowledge can attract capital (for a rent)

entrepreneurship, start-ups, grants, finance, loans

- *but capital can also buy knowledge (licensing, hiring)

patents

environments that promote collective knowledge, learning and “assembly” are key for growth: Cities !!

It is in such environments you will see: **diversity, interdependence, connectivity, learning, turnover, public institutions** resulting in experimentation and fast change.