Education, Research and Innovations

Predicting the Unpredictable

Yrjö Neuvo
3.11.2020

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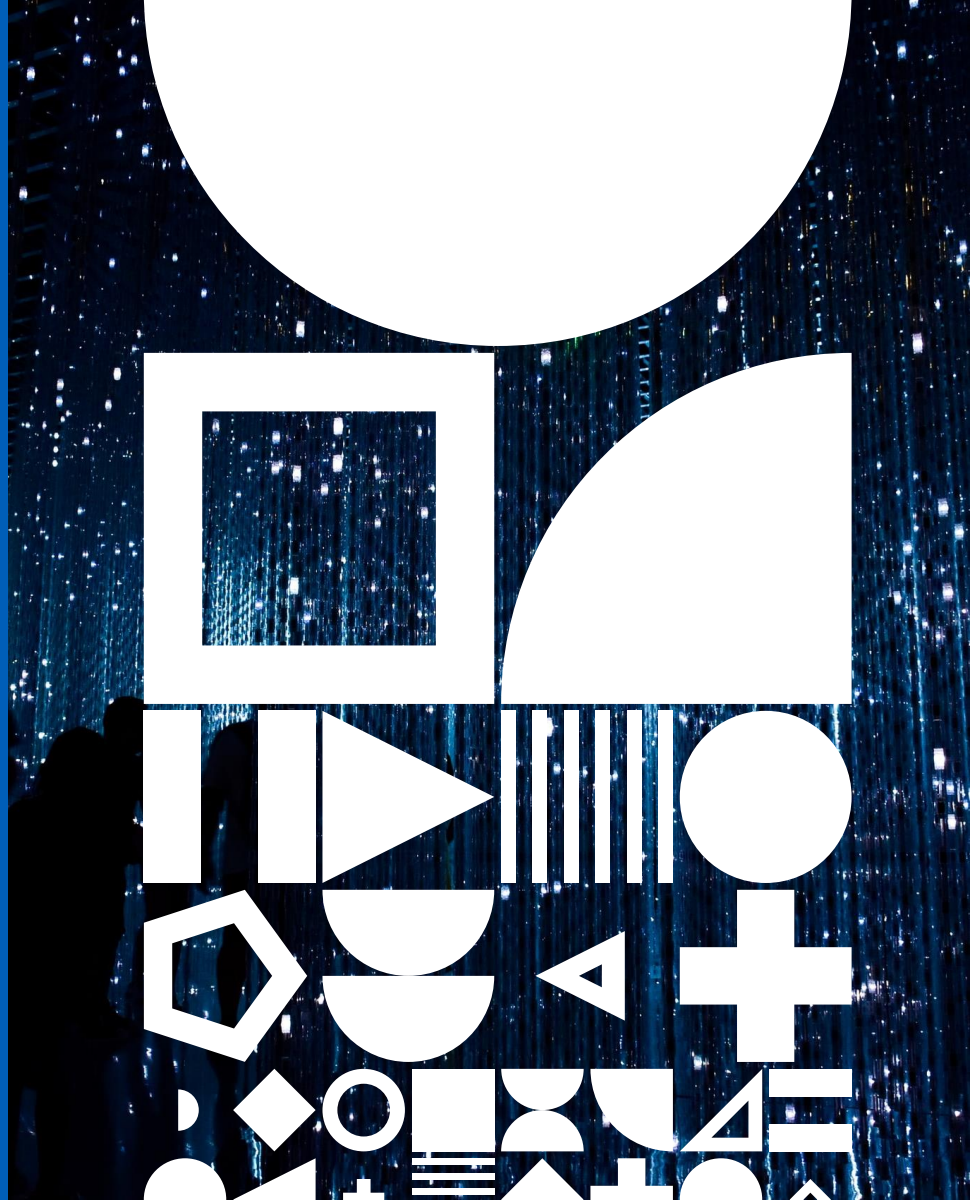
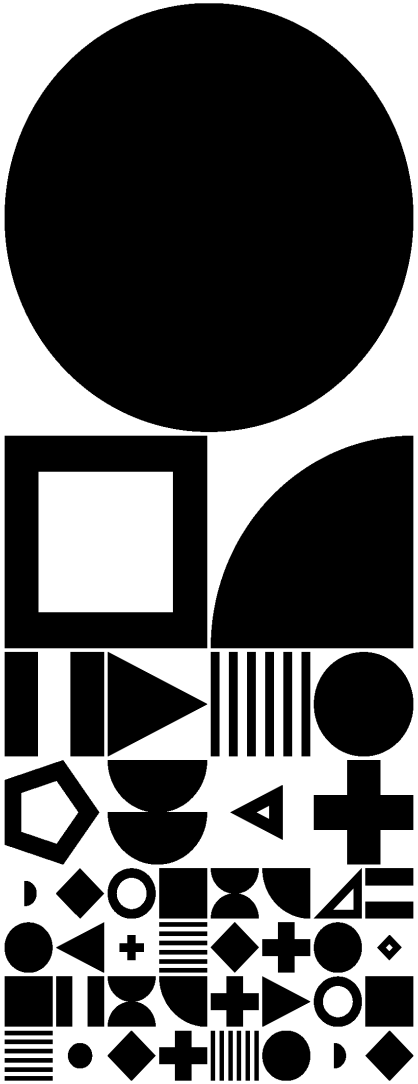


Moore’s Law (55 years old!)

Every two years:

- **Speed and number of transistors double**
- **Power consumption and cost of transistor halves**

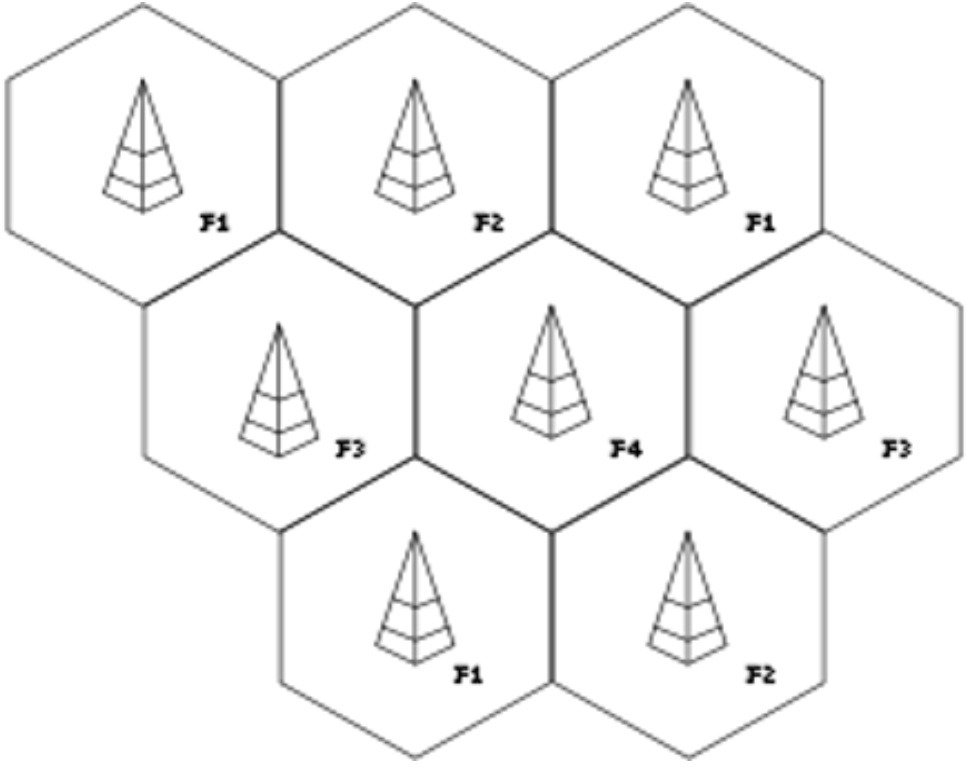


“But it is not only Microelectronics that improve exponentially over time”

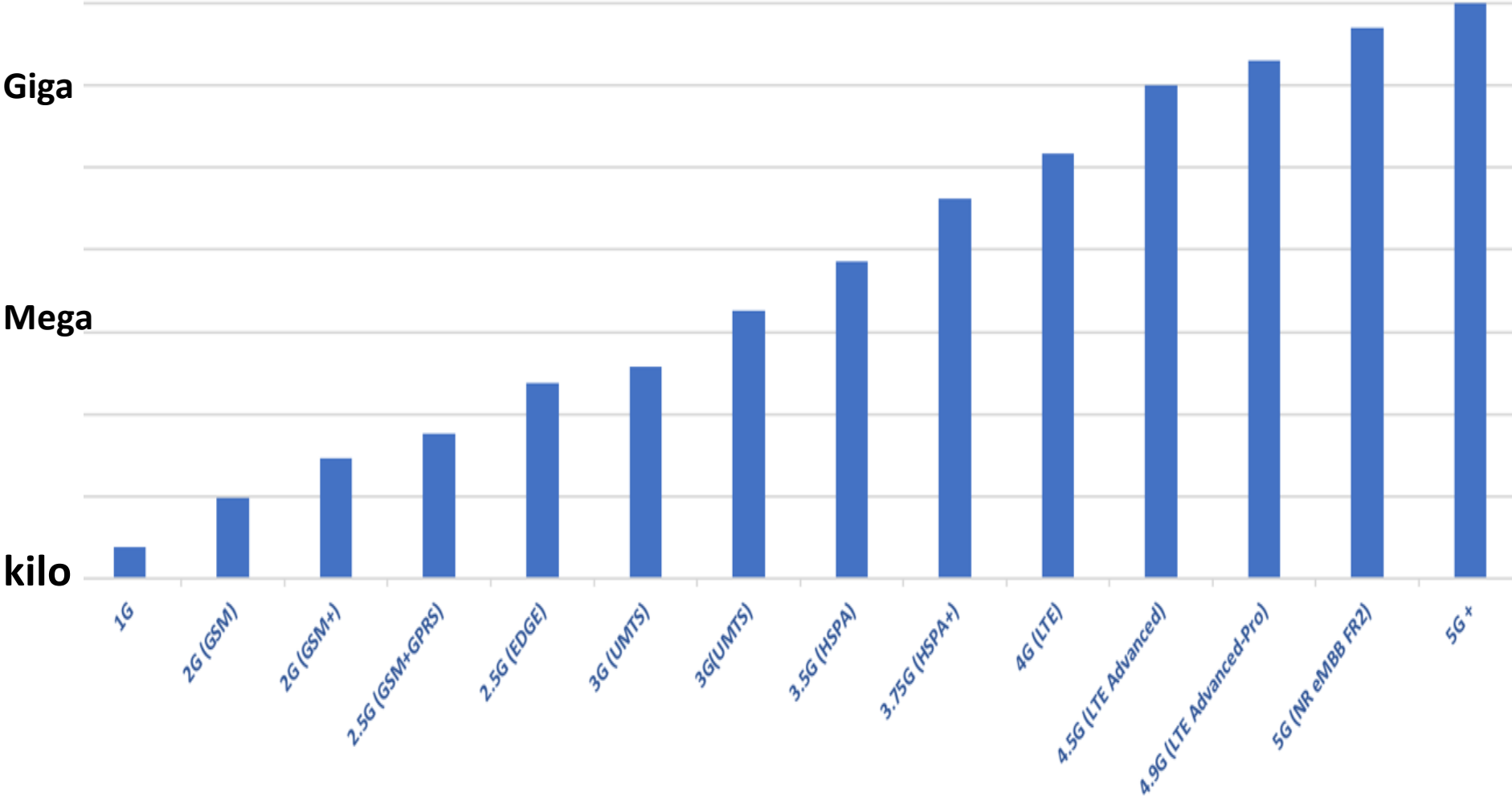
Mobile Networks' "Moore's Law"

(Is radio bandwidth really a limited resource?)

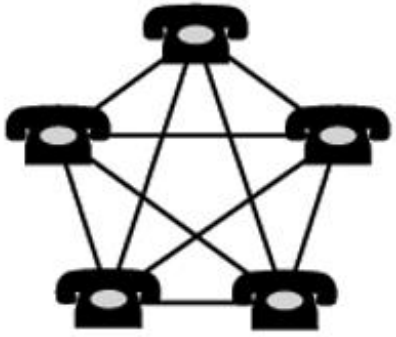
Smaller cell sizes bring capacity, speed and more frequencies

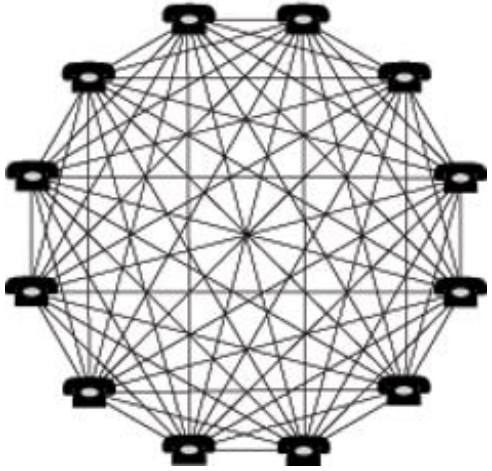


Mobile data speed has doubled every 19 months!




And 6G is already on the drawing board





Metcalfe´s Law

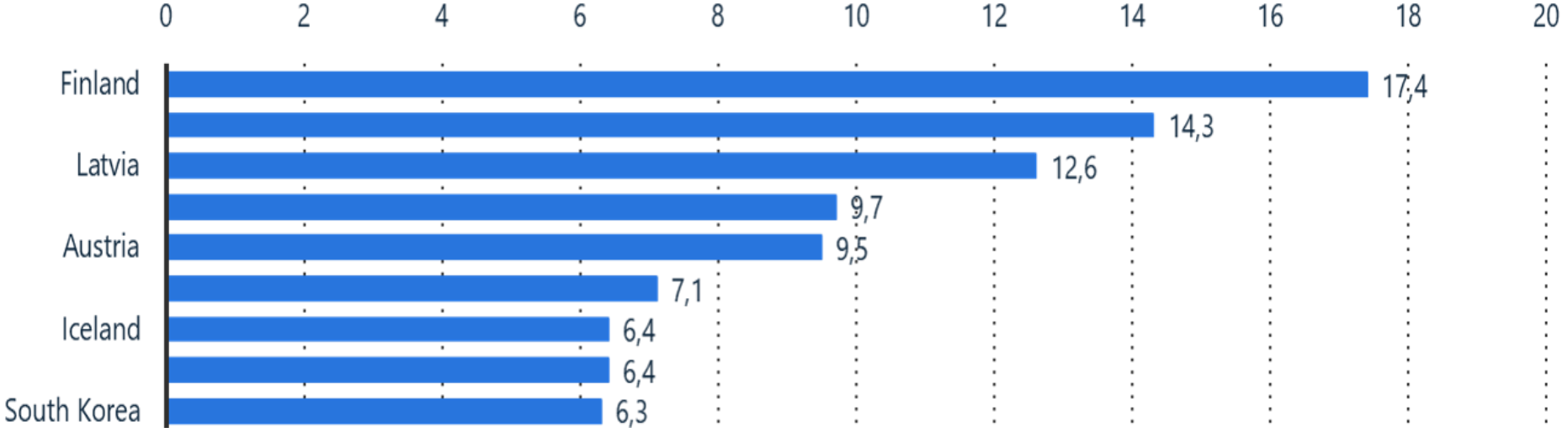
Utility and value = users^2

The first solution to reach critical mass wins

“Finland is full of Telephones”

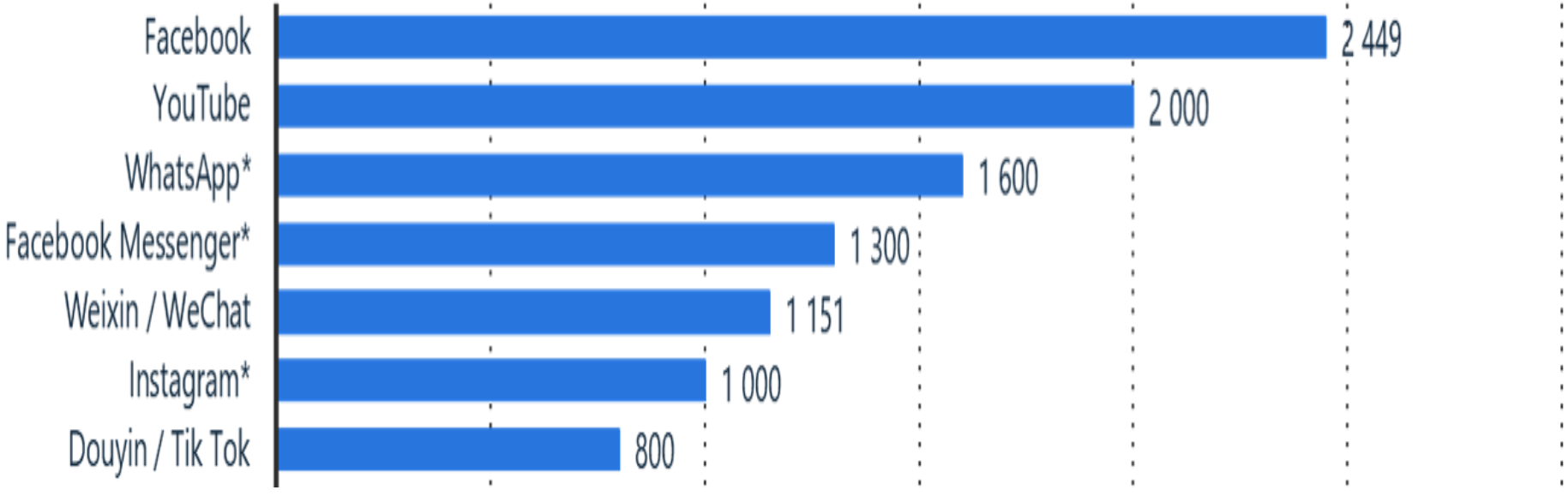
Through Finland in Carts 1896 by Mrs Alec Tweedie

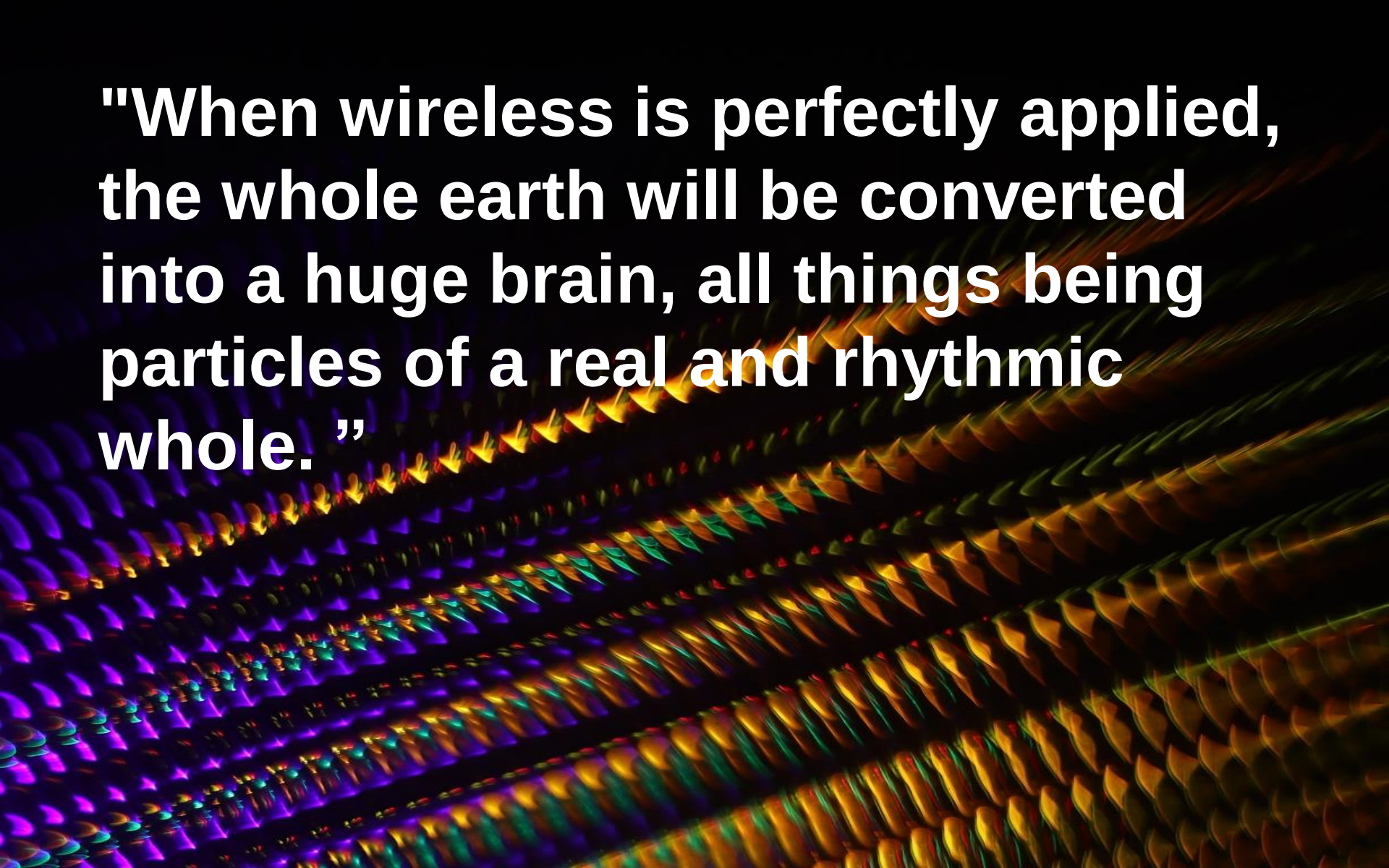
Worldwide monthly mobile data usage in 2018, by country (in GBs per SIM)



Most Popular Social Networks Worldwide

Number of active users in millions as of January 2020

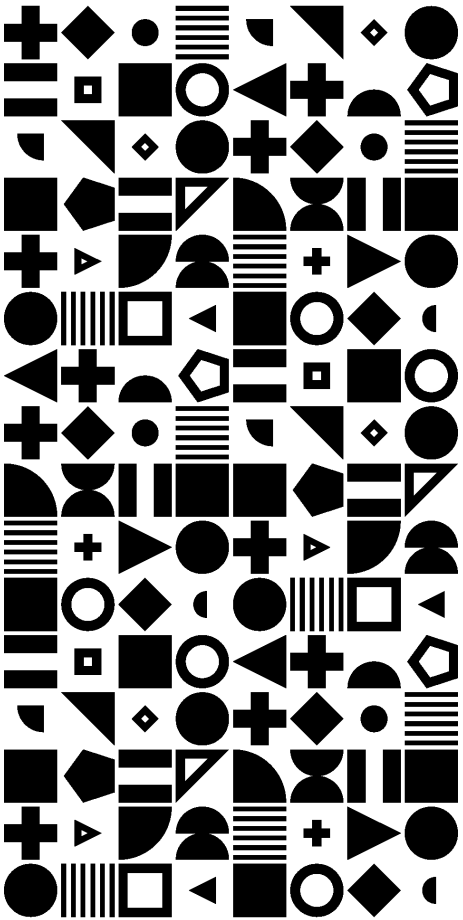



"When wireless is perfectly applied, the whole earth will be converted into a huge brain, all things being particles of a real and rhythmic whole. ”

Nikola Tesla 1856 – 1943

- Throughout the 1890s, Tesla pursued his ideas for worldwide **wireless electric power distribution** in his high-voltage, high frequency power experiments in New York and Colorado Springs.
- In 1893, he made pronouncements on the possibility of **wireless communication** with his devices.
- Tesla tried to put these ideas to practical use in his unfinished **intercontinental wireless communication and power transmitter project.**

Role of Basic Research



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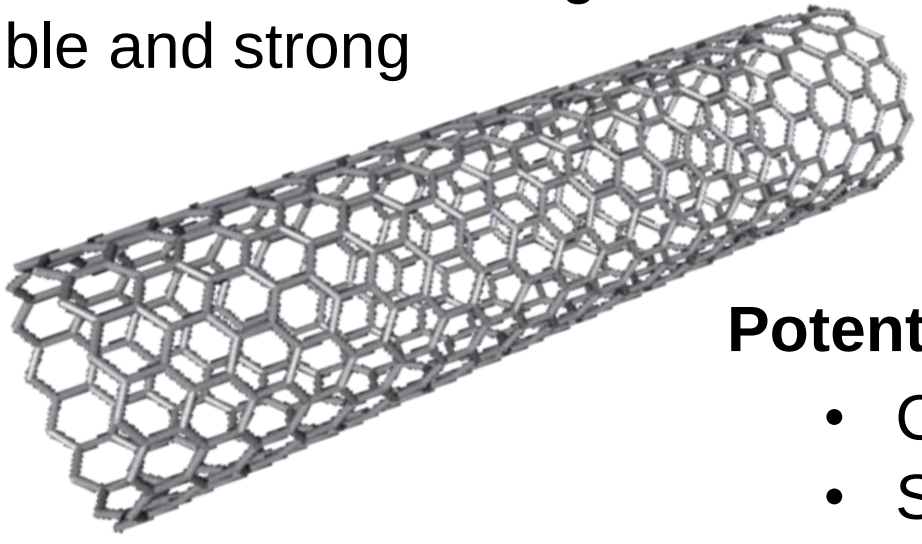
Carbon Nanotube Transistor?

- Self-assembled perfect 1D wire
- Metallic / Semiconducting
- Flexible and strong



Potential applications

- CMOS devices in VLSI
- Sensor devices
- RF devices in THz
- Flexible TFTs

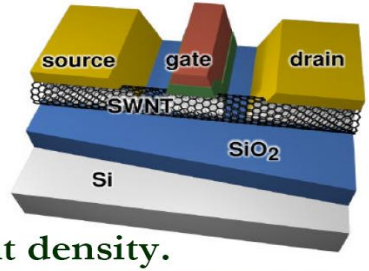
World Wide Economic Activity Associated With Electronics*

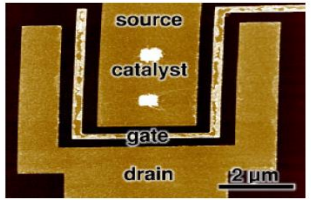
*Phaedon Avouris, IBM, 3/2006

- Semiconductors 215 B$
- Electronics 1 T$
- IT enabled services 5 T$

CNT transistor
-Advantage-

- High speed operation is expected.
  g_m ~10000 μS/μm[1] (p-Si x ~20)
- Excellent durability to large current density.
  $10^{9\sim10}$ A/cm^2 (Si x ~100)
- Compatible with high-κ gate oxides.
  HfO_2[1], $SrTiO_3$[2]…
- Low cost substrate can be used.
  Polymer[3]

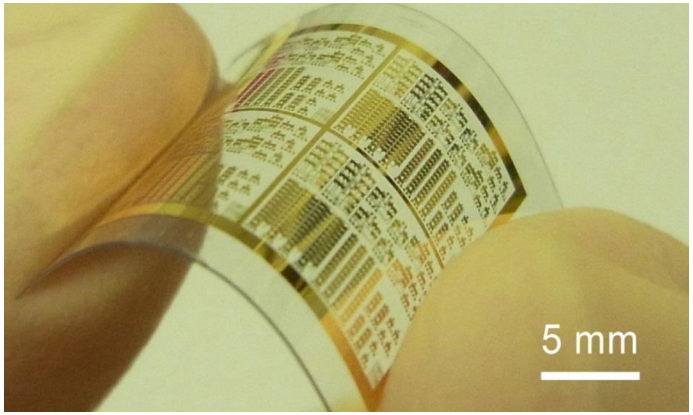


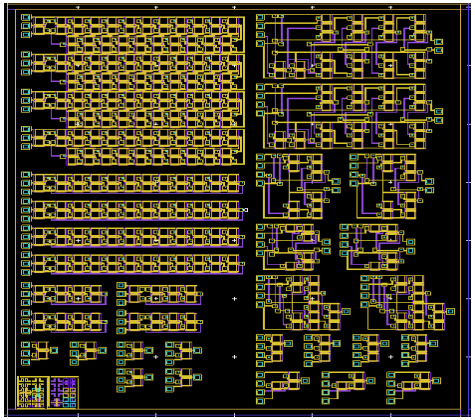


Nihey et al, JJAP 2004

From Ishida et al., NEC, NT05

First Nanotube Integrated Circuit





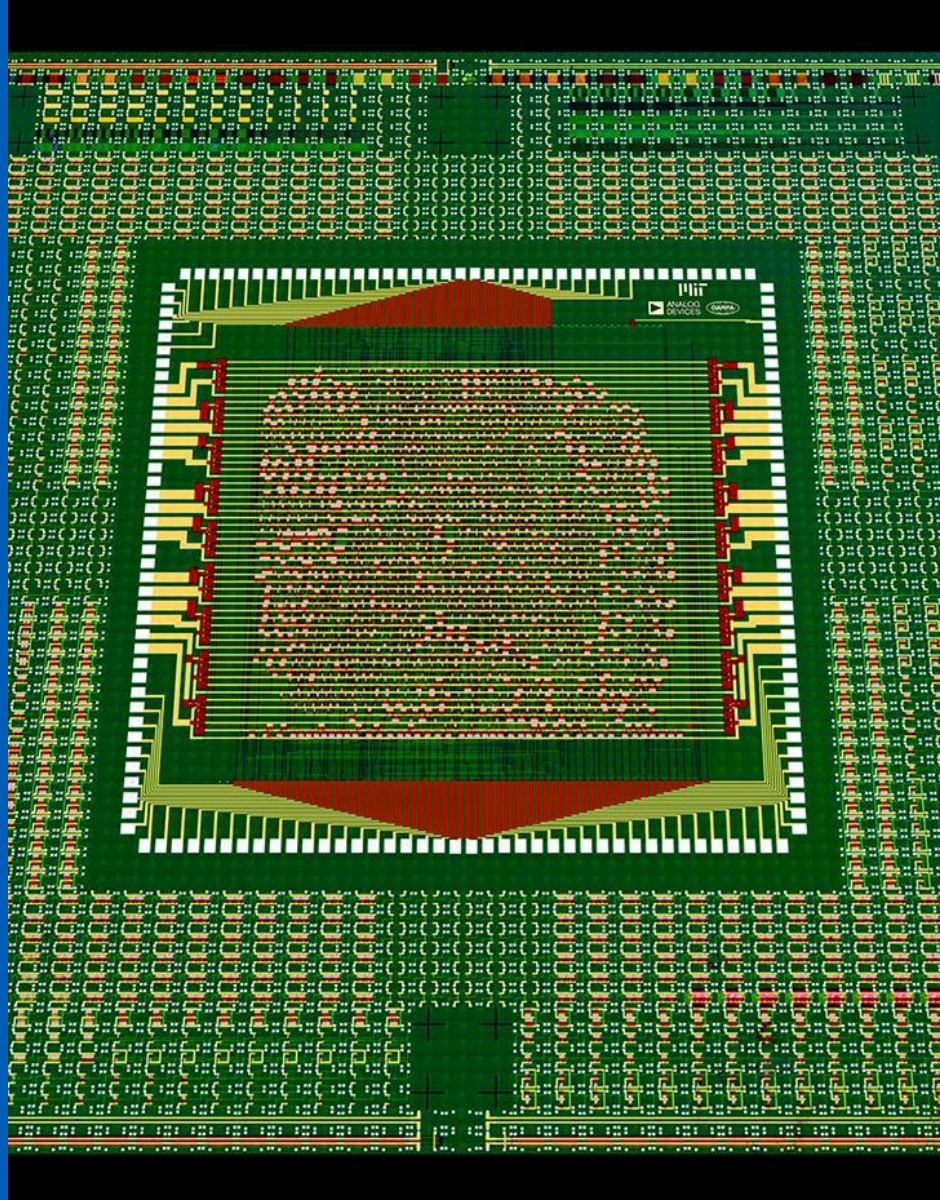
- Inverters
- Ring oscillators (3, 11, 21 stages)
- NOR and NAND logic gates
- RS- and D- flip-flops

Sun *et al*,*Nature Nanotechnology* (2011) **6**

Enough to Say Hello

Engineers at MIT and Analog Devices have created the first fully-programmable 16-bit carbon nanotube microprocessor.

It’s the most complex integration of carbon nanotube-based CMOS logic so far, with nearly 15,000 transistors.



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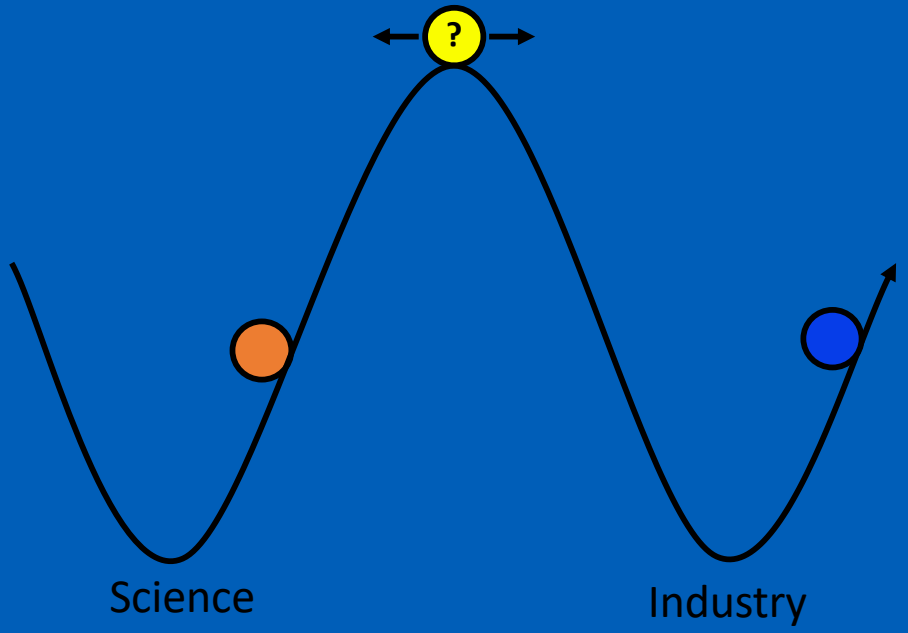
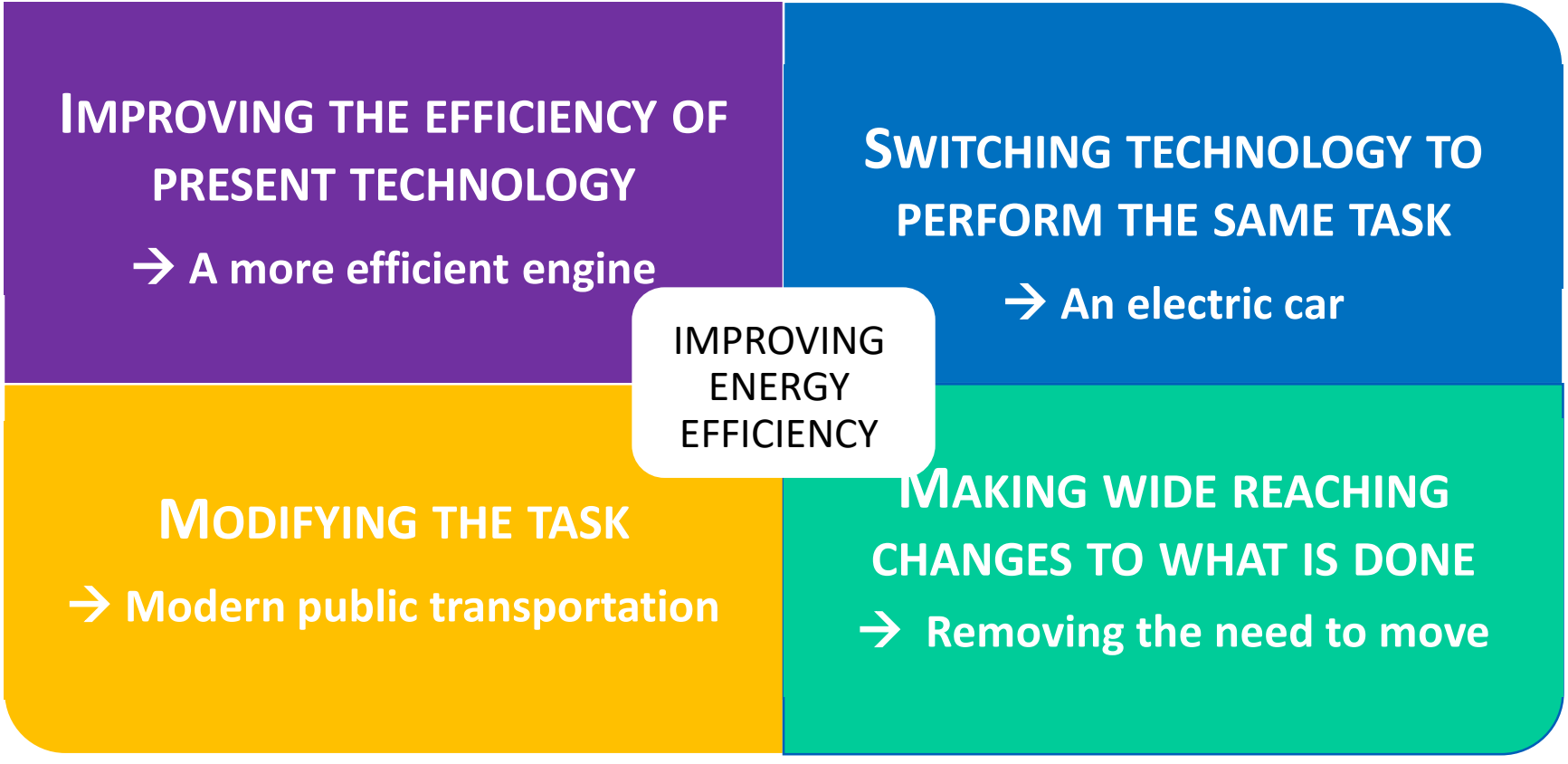
(Doctors') Career Paths

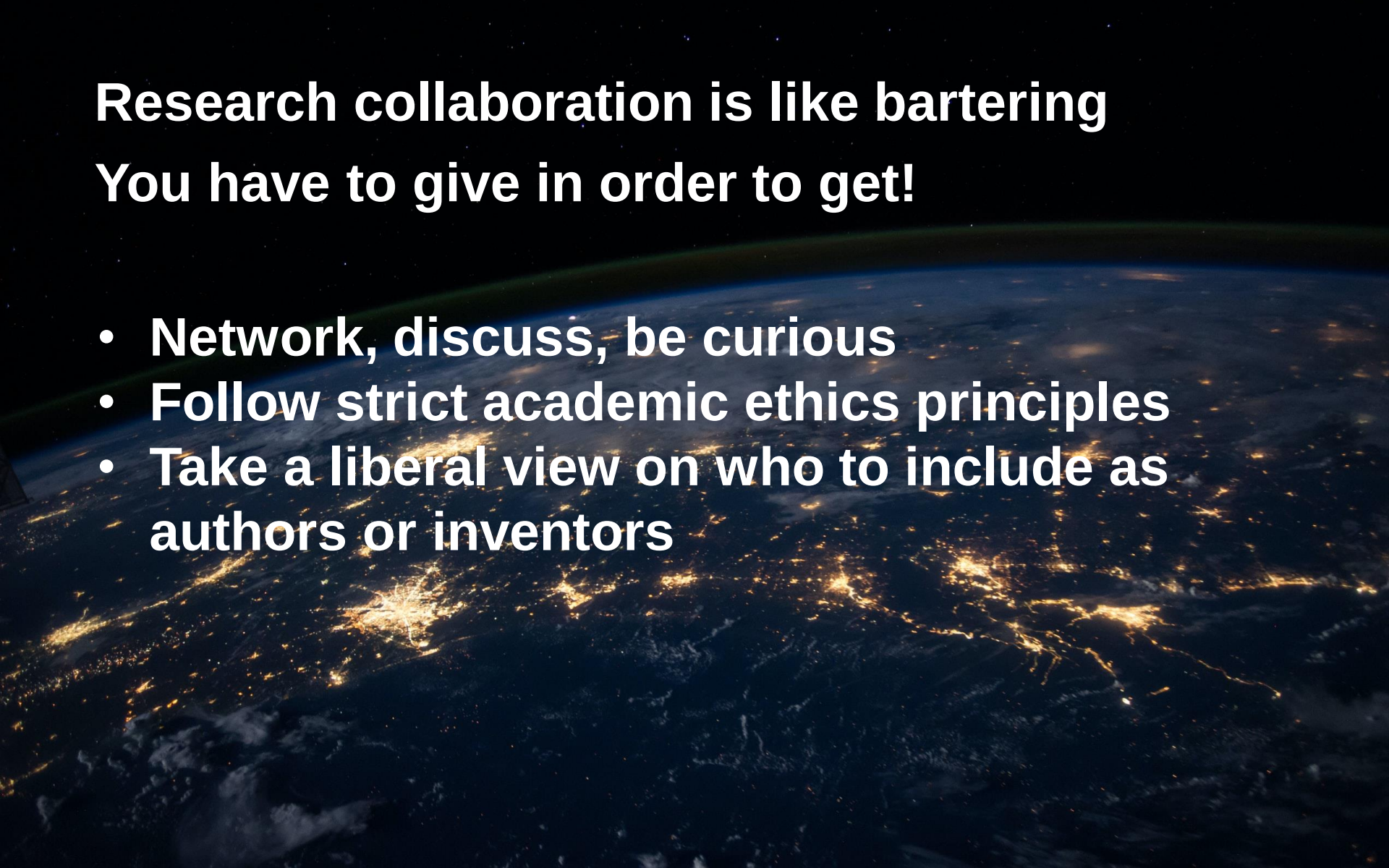
Theory or Practice?
Industry or Academia?

It is not either or,
but both and!



Think Broadly!





Research collaboration is like bartering

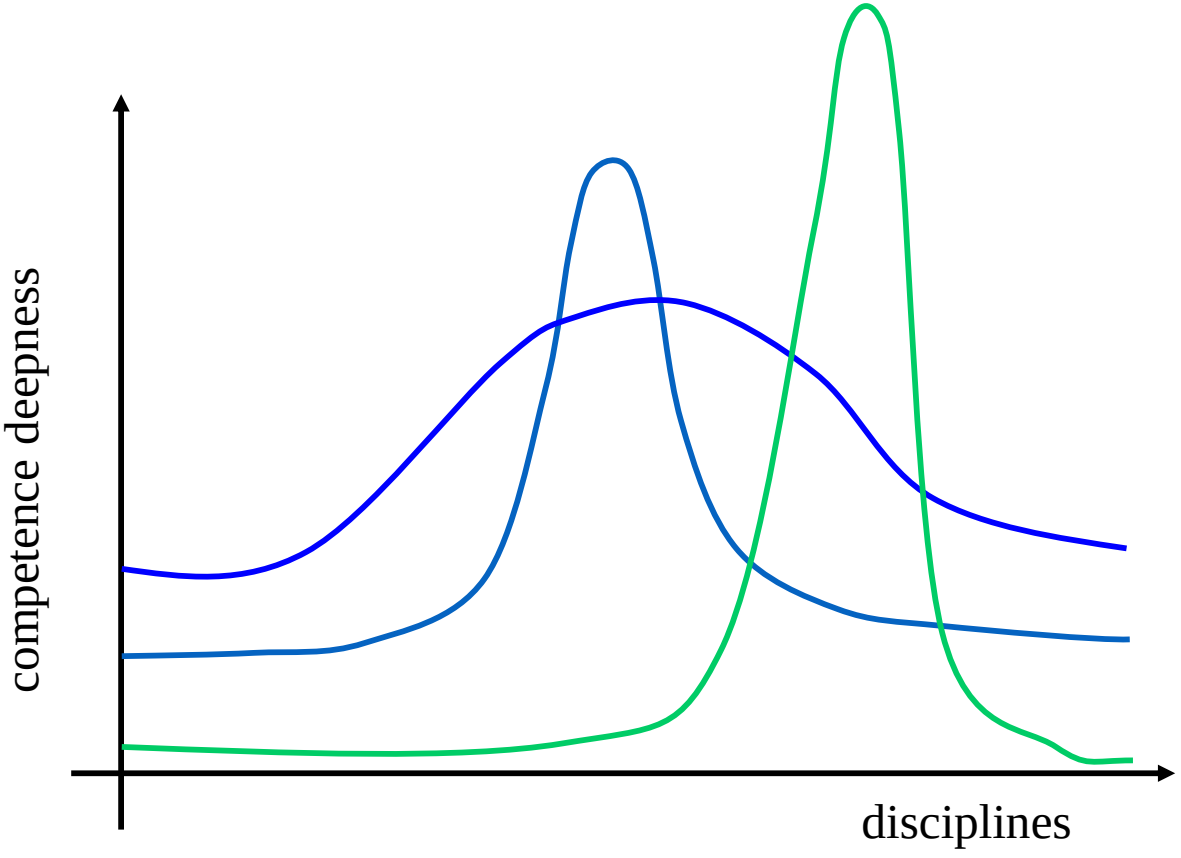
You have to give in order to get!

- **Network, discuss, be curious**
- **Follow strict academic ethics principles**
- **Take a liberal view on who to include as authors or inventors**

Competence (Curiosity) Profile

Deep competence in a specific area or understanding the bigger picture

Both **breadth and depth** are needed



Grow Your Knowledge Capital!

- **Continuous learning is like putting money in the bank.**

- Capital after t years with interest rate r
- Time in years to grow the capital from C1 to C2
- Aproximate time to double the capital:

$$C_2 = C_1 \cdot e^{rt}$$

$$t = \frac{100 \times \ln(C_2 / C_1)}{r\%}$$

$$t_{\times 2} \cong \frac{70}{r\%}$$

Career Planning

- Like what you do, career planning less important
- At young age, test your limits, do radical things
- Sacrifice short term economic benefits…
- Go abroad

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Thank you!

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