



Max Planck Institute  
for Innovation and Competition

# Recombination and General Purpose Technologies

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# Agenda

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- Recombination
- General Purpose Technologies:
  - Characteristics of GPTs
  - GPT Adoption



# Examples of Innovation

## “The electric candle” (Edison 1880)

- Electricity passing through a filament in vacuum
- Edison carbonized 6000 different organic materials for the filament, eventually choosing Japanese bamboo



# Examples of Innovation

## “The electric candle” (Edison 1880)

- Electricity passing through a filament in vacuum
- Edison carbonized 6000 different organic materials for the filament, eventually choosing Japanese bamboo



## “Self-driving cars” (Google and others 2000s)



- Cameras and sensors collect data on surrounding
- “Correct driving” is learnt by imitating a trained human driver, building a deep network through “reinforcement learning”

# Examples of Innovation

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## “Imaging camera pill” (Iddan 1994)

- Military image sensor from a missile placed in pill
- If swallowed, transmits video images of the intestine



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## “Smartphone” (IBM “Simon” 1992 or iPhone 1 Apple 2007?)



vs.



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- Mobile Phone with
- Computer-like operating system



# Regularity?

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# Regularity?



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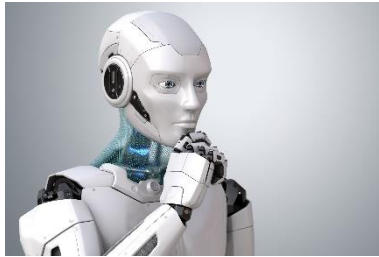
# Regularity?



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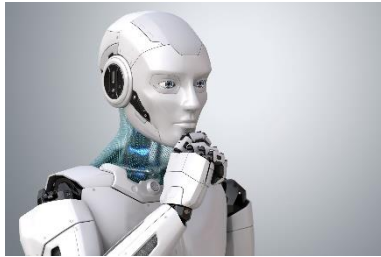
# Regularity?



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# Recombination

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## The ultimate source of novelty?

- “What is mathematical creation? [..] Precisely in **making combinations which are useful**, which are a small minority. Invention is discernment, choice [..] Among combinations, the most fertile will often be those formed elements drawn from domains which are **far apart**.” (Poincare 1908)
- “Invention finds its distinctive feature in the constructive assimilation of **preexisting elements into new syntheses**, new patterns, or new configurations of behavior.” (Usher 1927)



# Recombination

## Uzzi, Mukherjee, Stringer, Jones (2013): “Atypical combinations and scientific impact”

- Consider the **pairwise combination of journals in the references** of an article
- Rank for each paper all pairs by the “commonality” score (higher=more common)
- “**Conventionality**” = how high is the median score across all pairs?
- “**Novelty**” = how low is the 10<sup>th</sup> percentile of the score across all pairs?

### References and Notes

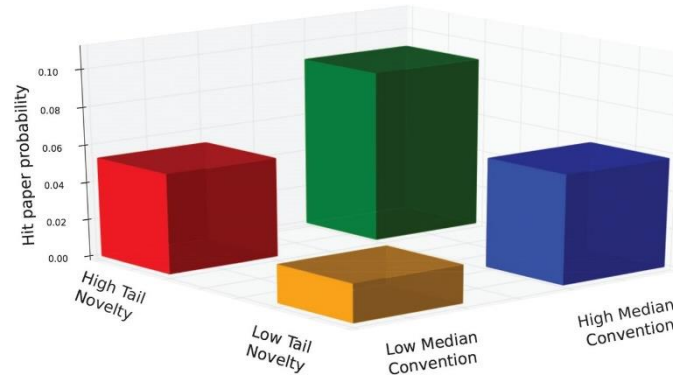
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# Recombination

Uzzi, Mukherjee, Stringer, Jones (2013): “Atypical combinations and scientific impact”

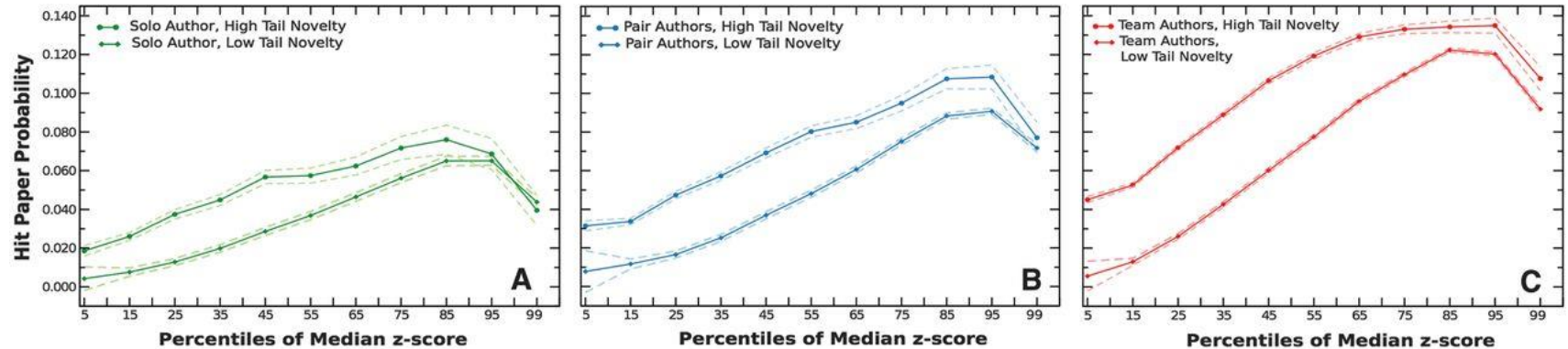
**Result 1:** Probability of impactful “hit” paper is particularly high when there is  
+ high “novelty” (i.e. **low 10<sup>th</sup> percentile commonality** score)  
+ high “conventionality” (i.e. a **high median** commonality score)  
in referenced journal pairs.



# Recombination

Uzzi, Mukherjee, Stringer, Jones (2013): “Atypical combinations and scientific impact”

- **Result 2:** The relationship is monotonic (for both factors) almost across the entire range of values



# Recombination

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Uzzi, Mukherjee, Stringer, Jones (2013): “Atypical combinations and scientific impact”

- “The highest-impact science is **primarily grounded in exceptionally conventional combinations** of prior work **yet simultaneously features an intrusion of unusual combinations.**”
- “**Beyond science, links between novelty and conventionality in successful innovation also appear.** E-books retain page-flipping graphics to remind the reader of physical books, and blue jeans were designed with a familiar watch pocket to look like conventional trousers.”



# Recombination

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## Discussion

- Why could this be?





# Recombination

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- Why could this be? Some guesses..
  - Human mind may be “hard-wired” to distrust new or unfamiliar things.  
“Conventionality” helps others gain trust und build familiarity
  - Historical examples suggest that major breakthroughs are not revolutionary, but rather integrate different strands of pre-existent knowledge (e.g. Relativity Theory)
- Do you believe that most innovations are a combination of things that were already there? What is “genuinely new” then?



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- Do you believe that most innovations are a combination of things that were already there? What is “genuinely new” then?
  - Where do ideas come from, if not from experiential knowledge?
  - E.g. music reflects the influences of the musician



# General Purpose Technologies

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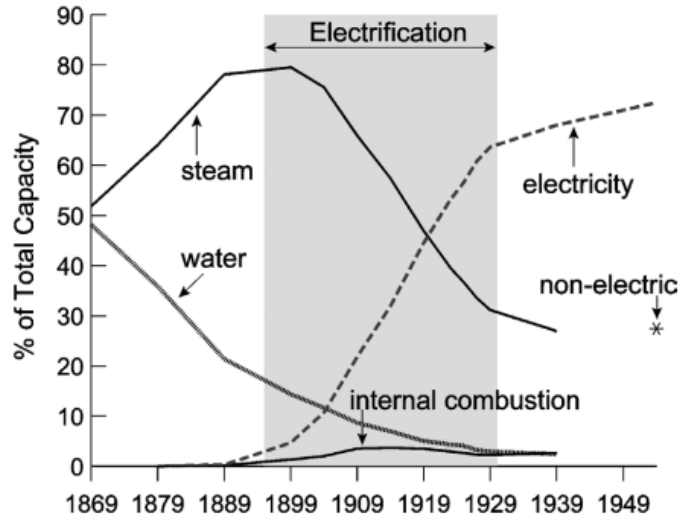
## Definition

- Technologies that have vast potential to be recombined
- Characteristics of a **General Purpose Tech.** (Bresnahan and Trajtenberg 1996):
  - **Pervasiveness:** spreads across most economic sectors
  - **Innovation complementarity:** facilitates the invention of new related products and processes
  - **Improvement:** large inherent potential to improve over time
- Examples: Steam (1860-1890), Electrification (1890-1930), IT (1970-2000)



# General Purpose Technologies

## Pervasiveness: The Electrification Era



### Note:

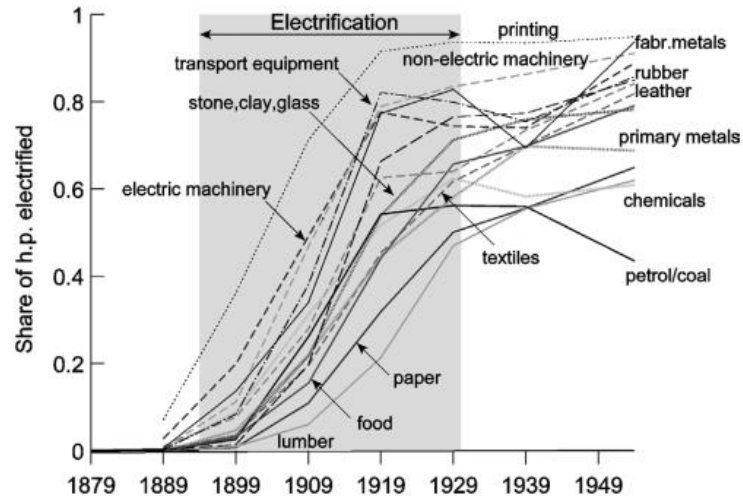
- Electricity does not overtake water until ~1900, and does not overtake steam until ~1920 in importance

Share of horsepower generated by source in US manufacturing (Jovanovic & Rousseau 2005)



# General Purpose Technologies

## Pervasiveness: The Electrification Era



### Note:

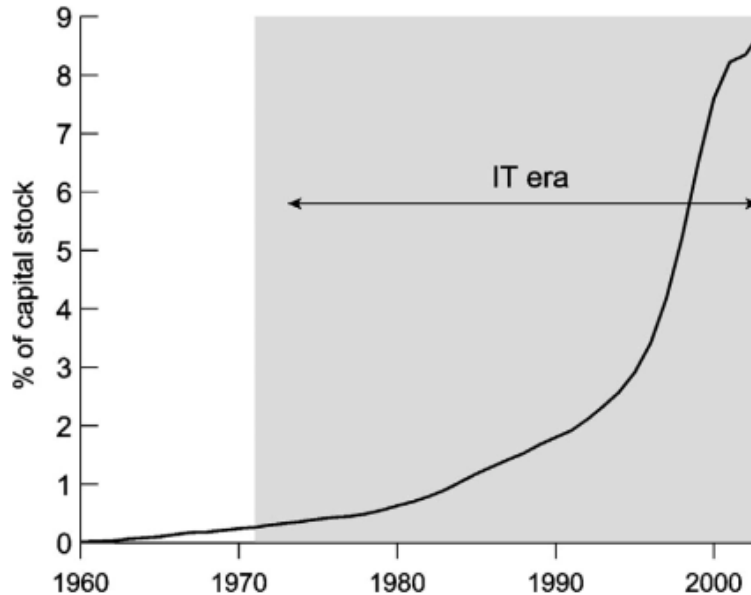
- The “beginning of the Electrification Era” is defined as the year in which the median sector sourced at least 1% of its horsepower from electricity

Share of electrified horsepower by manufacturing sector (Jovanovic & Rousseau 2005)



# General Purpose Technologies

## Pervasiveness: The IT era



### Note:

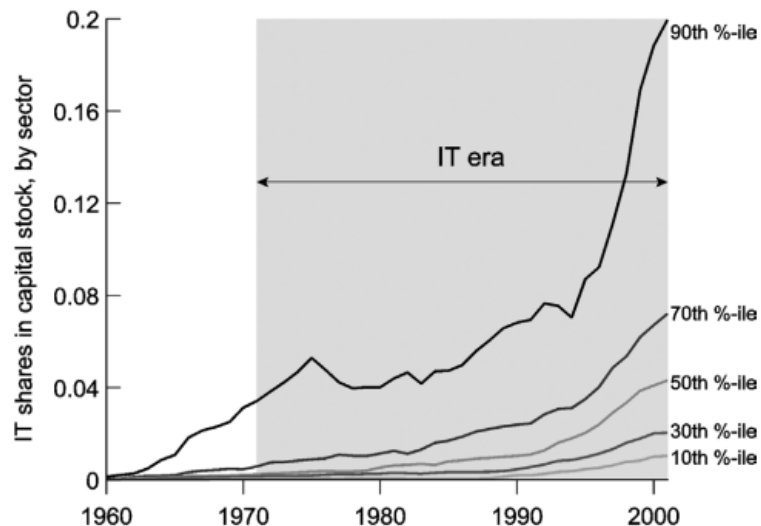
- The “pervasiveness” of IT in the economy is measured relative to “other capital”

Share of computer equipment and software in capital (Jovanovic & Rousseau 2005)



# General Purpose Technologies

## Pervasiveness: The IT era



### Note:

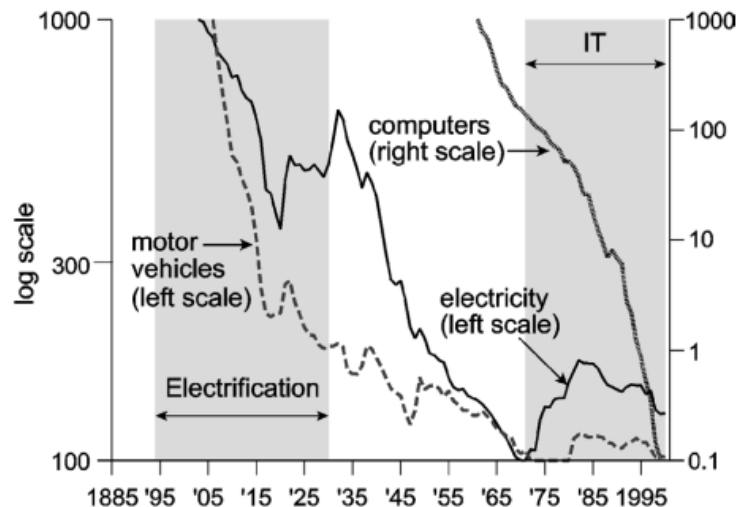
- In 1970, the median sector had at least 1% of its capital stock composed of software or computer equipment

Share of computer equipment and software in capital by sector in percentiles (Jovanovic & Rousseau 2005)



# General Purpose Technologies

## Subsequent improvements of the GPT



Price index for electricity (left scale) and computers (right scale) (Jovanovic & Rousseau 2005)





# General Purpose Technologies

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## Innovation complementarity

- Country-level evidence in the US (Jovanovic & Rousseau 2005):
  - Higher ratio of Initial Public Offerings (IPOs) in total stock market value during the onset of electrification
  - Patenting activity surges between 1900 and 1930, and then again after 1977.
- Comparing GPT technologies with other technologies:
  - Hall and Trajtenberg (2004) suggest that 90% of the most broadly cited patents are ICT patents
  - However, Moser and Nicholas (2004) suggest that chemical patents in the 1920s saw more subsequent citations than electricity patents



# General Purpose Technologies

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## Symptoms of GPT eras (Jovanovic & Rousseau 2005)

- Productivity slowdown: retooling with technologies that complement the new GPT
- Increased Firm entry and exit
- Skill Premium for workers rises
- Stockprices drop
- Age of “leader firms” declines



# GPT Adoption

What defines the “beginning” of a technology or a GPT?

IBM “Simon” (1994)



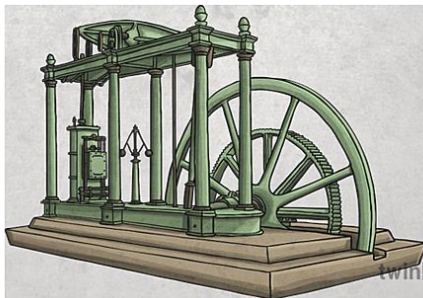
vs.

iPhone (2007)



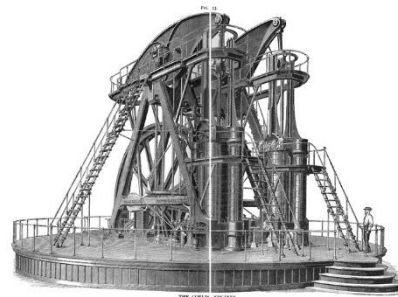
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James Watt’s Steam Engine (1775)



vs.

Corliss Steam Engine (1849)



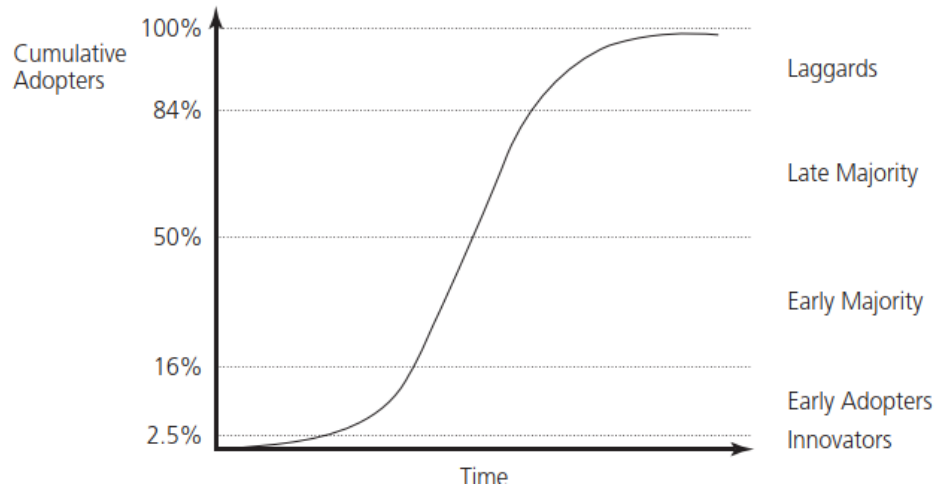
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- Criterion suggested by Jovanovic & Rousseau (2005):
  - Year in which the median sector used the technology to a marginal extent

# GPT Adoption

## The “S-Curve” in Technology Diffusion

S-curve of Cumulative Adopters



- Early Adopters
- Early Majority
- Late Majority
- Laggards

“Diffusion” may refer to:

- Use of a GPT for an invention
- Use of a technology for production or consump.

S-Curve of Technology Diffusion, taken from Schilling (2013)



## The “S-Curve” in Technology Diffusion

- At home:
  - Download the dataset “Cross-country Historical Adoption of Technology (CHAT) (<http://www.nber.org/data/chat>)
  - Select a technology and a country - do you see a S-curve?
  - Compute the “adoption-lag”, the time between emergence and stagnation/saturation
  - Investigate possible hypothesis: Does the adoption lag vary by X? E.g. do countries where the technology emerges later adopt faster? Do countries with higher degrees of income inequality adopt slower if the technology is primarily embodied in consumption goods?



# GPT Adoption

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## The S-Curve in Diffusion

- The “S-Curve” in Diffusion appears to be an empirical regularity
- What may explain its shape, especially the acceleration phase?
  - **Complementarities:** e.g. improvements in computers stimulate improvements in software, which may stimulate further investment in computers
  - **Network externalities:** the usefulness may increase (more than linearly) in the number of users (mobile phone, platforms)



# GPT Adoption

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## Network Externalities and Complementarities

- Inefficiencies in technology diffusion when technologies are complementary
  - **Underinvestment**
  - **Coordination on sub-optimal equilibria**



## Network Externalities and Complementarities

- Setup
  - Suppose there is a GPT Technology A (e.g. microprocessor) and a set of Application Technologies Z1,Z2,.. (e.g. digital cameras, smartphone,..)
  - Technical improvements in A imply technical improvements in Z1,Z2,..
  - When the owners of Application Technologies invest, the market for the GPT technology grows, and hence the incentive to invest in GPT technologies grows



# GPT Adoption

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  - When the owners of Application Technologies invest, the market for the GPT technology grows, and hence the incentive to invest in GPT technologies grows
- **Underinvestment (Bresnahan & Trajtenberg 1995):** The owners of GPT technologies and the owners of Application Technologies underinvest (relative to the social optimum)
  - Neither technology owner internalizes the gains for the other owner



# GPT Adoption

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## Network Externalities and Complementarities

	Invest in Complement	Not Invest in Complement
Invest in Tech	(2,2)	(-1,0)
Not Invest in Tech	(0,-1)	(0,0)



# GPT Adoption

## Network Externalities and Complementarities

	Invest in Complement	Not Invest in Complement	
Invest in Tech	$(2,2)$	$(-1,0)$	<b>Nash-Equilibria</b>
Not Invest in Tech	$(0,-1)$	$(0,0)$	Not invest is an equilibrium!



# GPT Adoption

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## Network Externalities and Complementarities

- Investors in complimentary technology may not only fail to invest, but may also **coordinate on an inferior technology**



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- Investors in complimentary technology may not only fail to invest, but may also **coordinate on an inferior technology**
- **Nuclear power reactors** (Cowan 1990):
  - 90% of civilian nuclear power reactors use light-water
  - However, during the 1950s, light-water reactors were considered less safe and less efficient than heavy-water reactors and gas-graphite reactors
  - Why did light-water technology prevail?
  - Answer: The US Navy forced General Electric to commit to light-water reactors in the 1950s, because of their usefulness in powering submarines

# GPT Adoption

## Network Externalities and Complementarities

### Providers of complementary technology

		Heavy water	Light water
General Electric	Heavy water	(3,3)	(1,1)
	Light water	(1,1)	(2,2)



**Nash-Equilibria**

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