Institutions and Multi-Agent Systems

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Resources

- My papers:
  www-personal.umich.edu/~jmm/

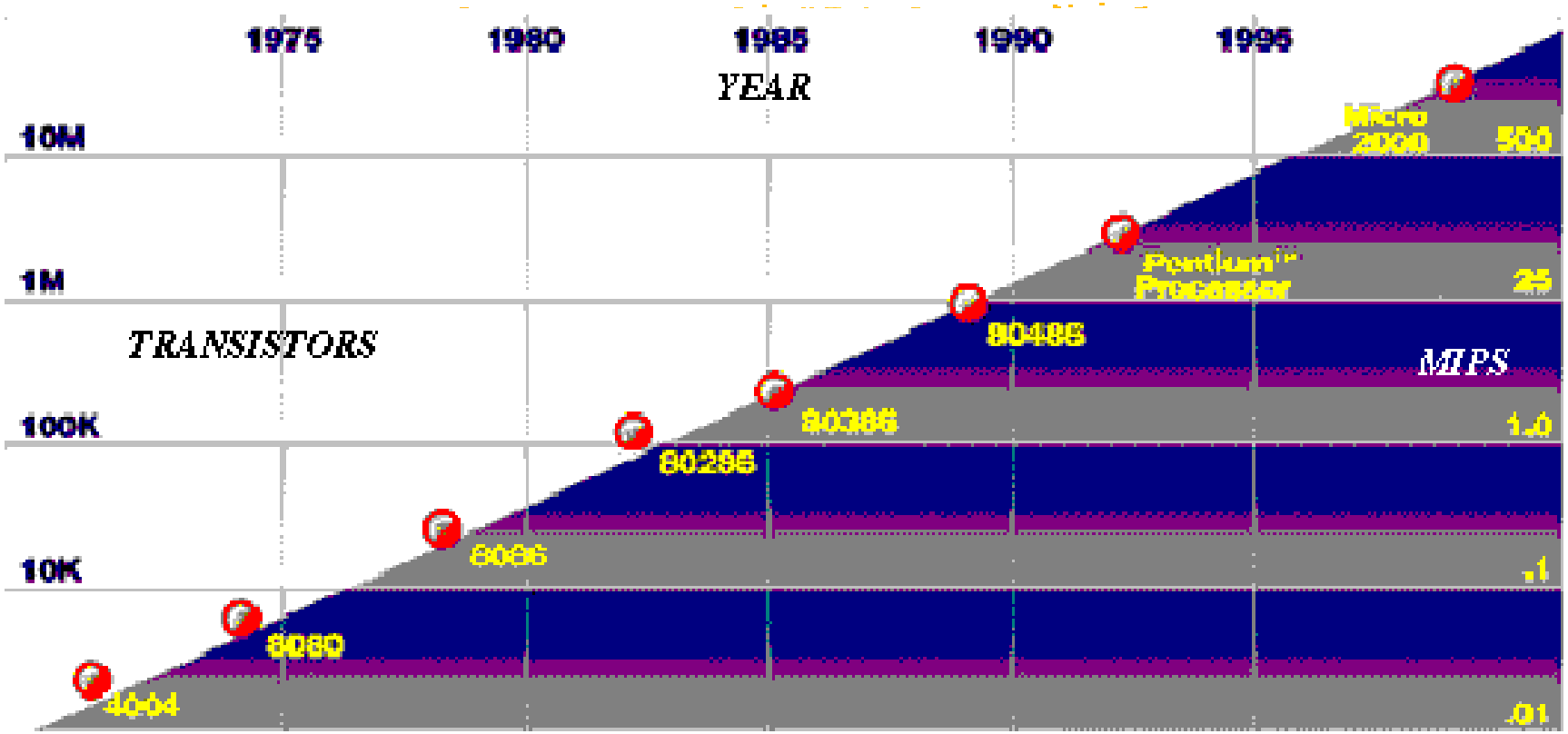
- Program for Research on the Information Economy (PRIE):
  www.si.umich.edu/~prie/

- MARX project:
  ai.eecs.umich.edu/MARX/



“The problem of bounded rationality is diminished by the use of cheap silicon and sand.”

Silicon

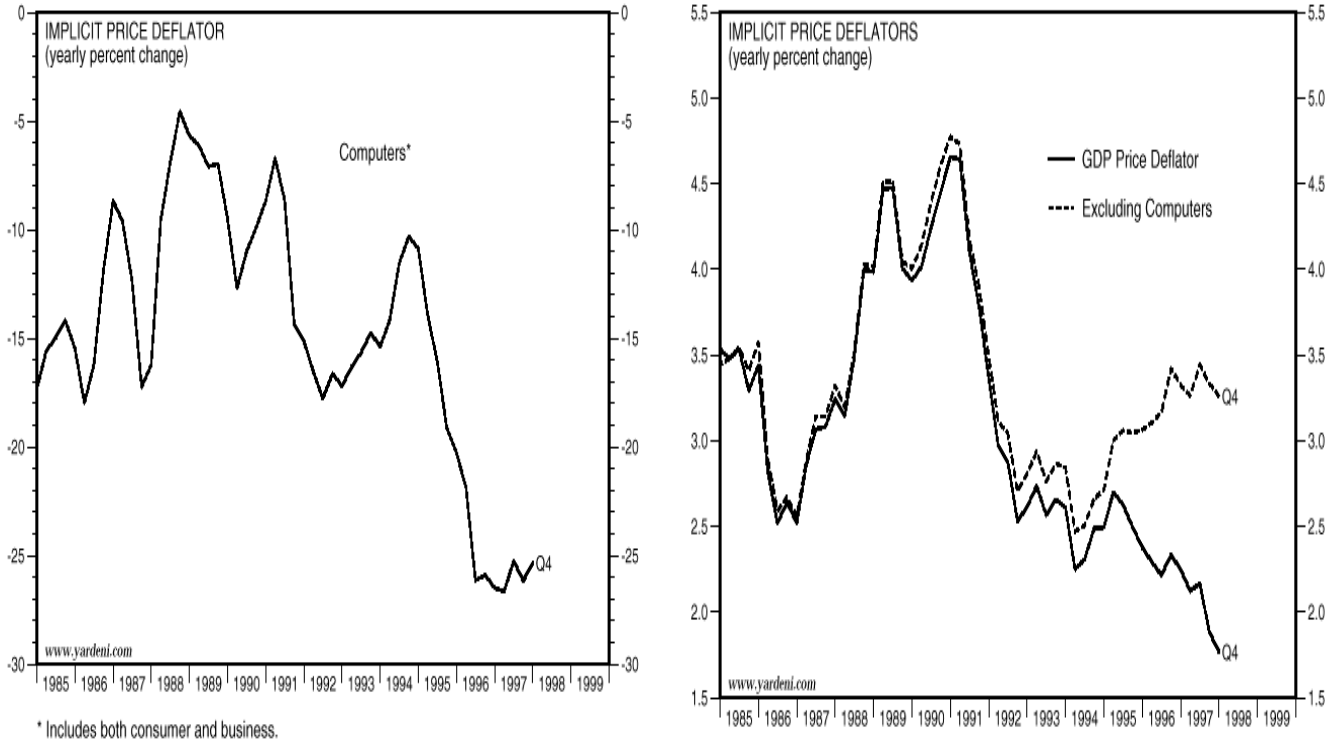


Transistor density doubling every 2 years since 1965

By Y2K, 100 million transistors, 1 billion instructions/sec

Source: Intel Corp.

Silicon Prices

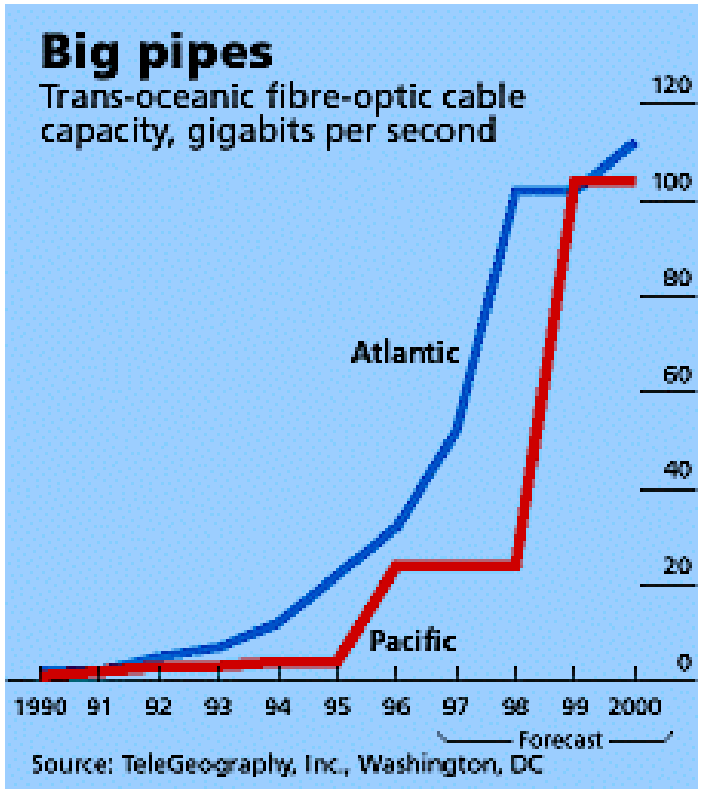


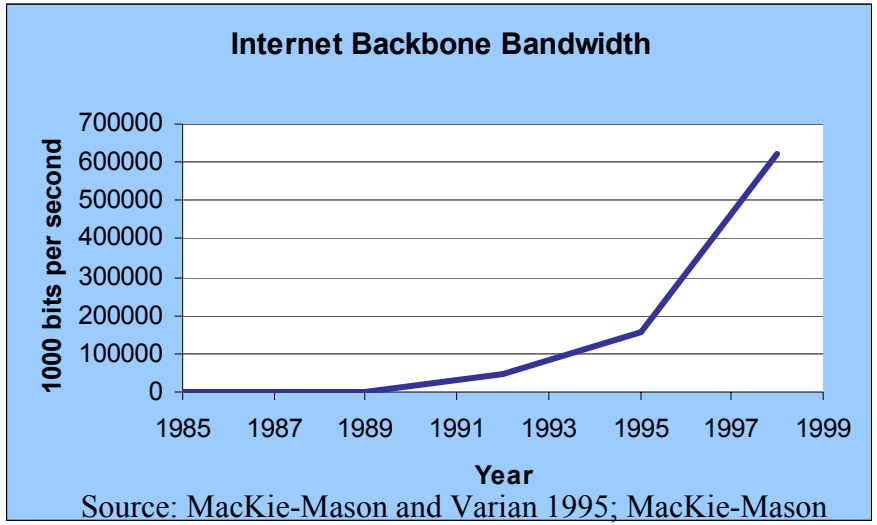
Computers: 5-20% price drop per year

GDP inflation: 3.25% without, 1.75% with computers

Source: Ed Yardeni, Deutsche Morgan Grenfell

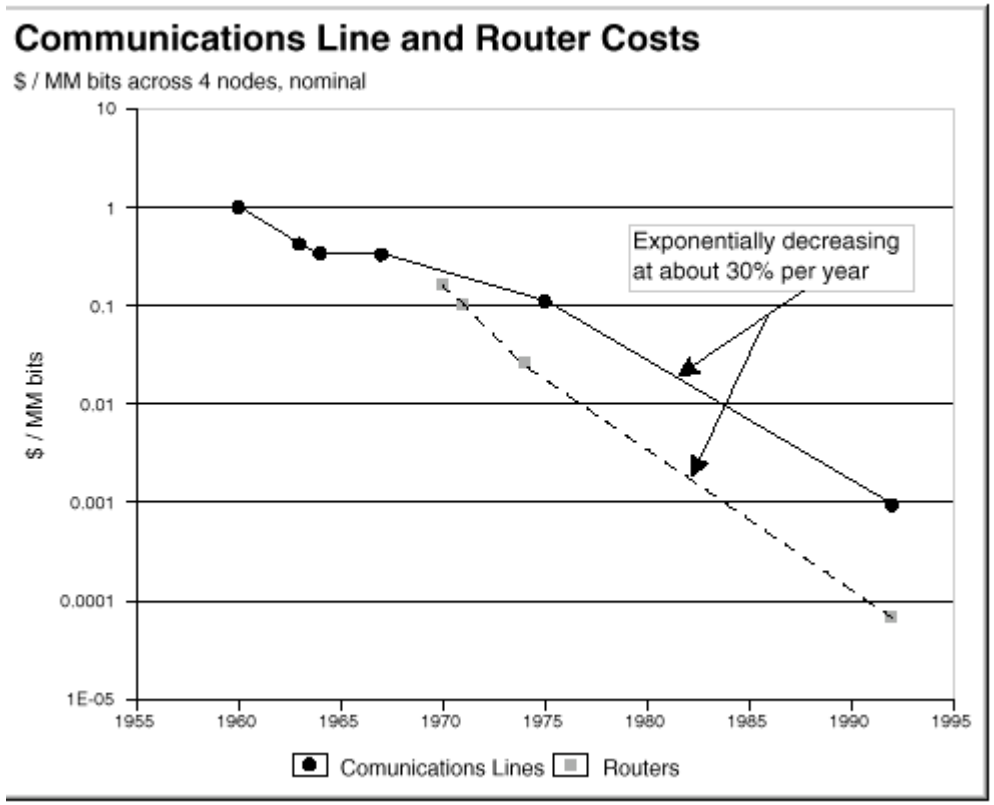
Sand





By mid-1999, Qwest will have a nationwide fiber backbone with more capacity than AT&T, MCI/Worldcom, Sprint combined

Sand Prices



Source: MacKie-Mason and Varian 1995

Would you use free communications?

Internet traffic growth:

	Jan-88	Nov-94
packets	85 Million	86 Billion

6% / month since early 1990s,
continuing at least through 1997
This is an annual doubling!

Source: NSF; MCI

What do these numbers mean?

- If faculty salaries fell 30%/year, a $125,000 **business prof would make $6000** in 10 years
- At 6% growth/month, Gates > GE in 23 months

Bill Gates	GM	GE
$71.47B	$45.97B	$277B

A research programme

- What could we do with free silicon and sand?
- Designing resource-allocating multi-agent cybersystems
  - To **solve problems**
  - To gain **fundamental insights** on the behavior of multi-agent (human and artificial) systems

Solving problems

- Designing interplay of **controlled and uncontrollable agents** to accomplish resource allocation goals
  - efficient network support for multiple QoS
  - automation and customization in e-commerce
  - electricity distribution
  - spectrum allocation
  - space lab / railroad / &c. scheduling

Harnessing multi-agent systems

- **First Welfare Theorem**: A competitive equilibrium is **Pareto efficient**
- **Second Welfare Theorem**: Any Pareto efficient allocation can be supported by a **competitive equilibrium**
- So:
  - make "economically-smart" agents who converge to competitive equilibrium
  - If desired, move endowments to obtain preferred allocation from Pareto set

Not too fast...

- Decentralized multi-agent systems provide **poor solutions** for distressingly fundamental problems
- Many fundamental problems have distressingly high computational **complexity**

Problem I: Poor solutions

- Competitive equilibria often **don't exist**, or **aren't efficient**
  - externalities
  - transaction costs
  - increasing returns
  - integer constraints
  - asymmetric information
- **Negative results** for more general mechanisms
- E.g., for 2-person exchange, **no** mechanism exists that is always guaranteed to be
  - efficient
  - non-coercive
  - no-deficit (Myerson & Satterthwaite)

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Practical mechanism design

- What **relaxed set of constraints** admits optimal solutions?
- Alternatively, how close do **admissible mechanisms** come to optimality?

Example: Application to scheduling

- How to harness computers and networks to solve scheduling problems?
  - priorities for network QoS
  - trains, planes, &c.
  - production lines for mass customization
  - task networks
  - electric grid spinning and wheeling
  - pollution rights

Simple case: Single slot demands (WWWM 1998):

- Optima exist
- Any optimal solution is **supported by a price mechanism**
- But not all price mechanisms are optimal
- How to find an optimum?

1. Ascending Single Good Auction

- Equilibria exist
- ASGA converges, **deviates from optimal by bounded amount**, proportional to ε
- NOW: With multiple slots, equilibria may not even exist!

2. Combinatorial Auctions

- Fully combinatorial auctions complex: 2^N different "goods" on which to bid
- Our new goods definition: pair(y,z) is y slots by deadline z, contains z
- Complexity = O(nL), L = max schedule length
- Finds equilibria for some problems not solved by ascending auction

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3. Generalized Vickrey Auction

- Varian and MacKie-Mason (1994)
- Pareto efficient
- If a price equilibrium exists, **GVA payments are no higher** than payments under minimum equilibrium prices (Gul & Stacchetti)
- If minimum reserve prices known, GVA for scheduling is participatory efficient in dominant strategies
  - If not, participatory efficient for M-1 agents (**market maker may run deficit**)

Scheduling roadmap

Mechanisms for scheduling

- single good ⇨ combinatorial ⇨ GVA

- increasing ---------->
  - scope of concerns
  - cases in which (near) efficient outcome found
  - computational complexity

Example: Web Caching

- What is the problem?
  - Rapid growth of convergent **multi-service** networks
  - Highly variable, **unreliable**, stochastic service quality
  - Increasing demand for multiple qualities-of-service (**QoS**)

Basic idea: QoS in distributed file services

- File storage characterized along several dimensions:
  - locality
  - reliability (incl. recency)
  - trade-off between them: fundamental economic problem
  - floppy, HD, CDROM, RAM….LAN, WAN...
- The more flexibly **user needs** for data access can be accommodated, the **higher the value**

Our first results

- Simple, **easy-to-implement** extension to standard LFU caching
- Provides **variable QoS**: higher valued file access obtains higher hit rate
- Provides **higher aggregate user value**

Cache Management Policies

- Users send messages to cache "manager"
  - object request
  - usage and forecast reports
  - bids and payments
- Cache implements several decisions as function of message:
  - **Replacement**
  - **Service**

Experimental data for swLFU

- 3 actual L3 Web cache request streams from NLANR project
- Palo Alto, Silicon Valley and University of Illinois (UIUC), 15-28 Aug 98

	Palo Alto	Silicon Valley	Univ Ill. Urbana-Cha
# servers	114,381	124,698	105,710
# URLs	3,412,105	3,744,274	2,884,598
# requests	7,011,622	7,897,659	5,568,112
Bytes requested	131,665,275,664	161,620,444,331	127,346,723,989
Value requeste	264,025,996,908,451	319,466,493,484,667	264,106,487,028,562
Infinite Cache			
size (bytes)	60,037,623,775	66,976,225,688	51,825,514,504
hit rate	51.3364	52.5901	48.1943
byte HR	54.4013	58.5596	59.3036
value HR	48.5422	57.467	56.5745

Results

- **higher value** than LRU, LFU
  - VHR 1/3 to 1/2 higher than LFU
- **better QoS** to servers that value it more
- worse on HR, BHR: not all hits created equal, so swLFU **trades off** BHR for higher aggregate user value
- NEXT:
  - designing deterministic replacement policy
  - analyzing incentives and free rider problems

Problem II. Complexity

- Even when theoretically possible, multi-agent systems may be intractably complex for problem solving

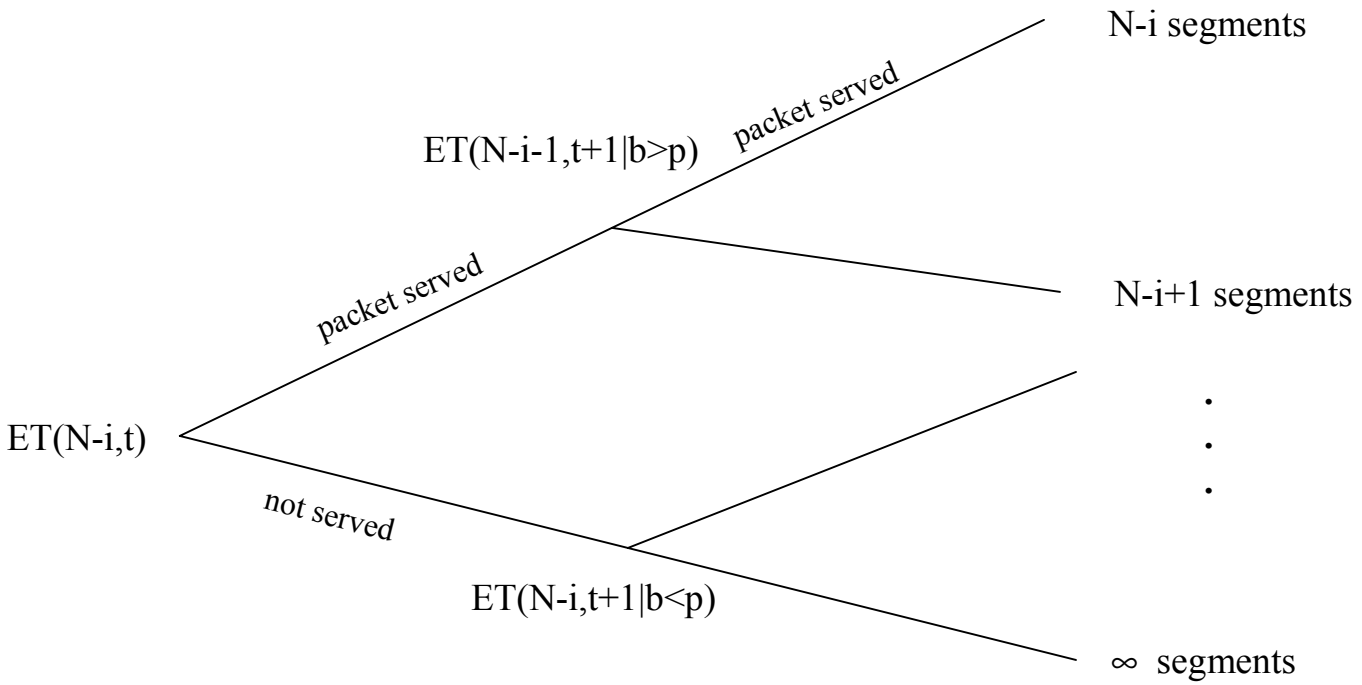
Example: Bidding for priority

- "Smart market" for gateway priority:
  - when congested, service the packet with the highest value for immediacy
  - agents bid their value for immediate service
  - assume a revelation mechanism

Mapping service value to priority

- How do agents **figure out** their valuations?
  - Suppose intrinsic value is for **completion time** (*T*) for N-packet flow
  - Need map from EU(T(N,t)) to reservation value for immediate service on first packet

Optimal bidding



Unbounded # of paths, with some branches of unbounded length. Each depends on updated beliefs about congestion, and on evaluation of sequence of continuation bids.

Complexity is the rule, not the exception?

- Many problems are **intractable**:
  $comp(\varepsilon,d) = o((1/\varepsilon)^d)$
  - utility maximization
  - expected utility maximization
  - finding competitive equilibria
  - finding rational expectations equilibria
  - option valuation
  - finding Nash equilibria
  - Rust 1997, and Traub et al. 1988

Re-examining the foundations

- Real economies can manage complexity…
  - What are they doing, and how?
- **Institutions** are essential
  - not all problems can be simultaneously endogenized
  - a dynamic version of **decomposition**
  - institutions are resource allocation mechanisms that **adapt at lower frequency**

Example of overlapping adaptive solutions

- Long-distance phone call
  - on-demand: spot market transaction
    - spot governed by trust conventions, language, &c.
      - governed by UCC and case law
        - governed by Constitution
        - &c.
  - long-term contracts: likewise…

Changing primitives change institutional imperatives

- As costs of silicon and sand plummet, the conditions underlying the design of existing institutions are invalidated
- The institutions themselves need to adapt

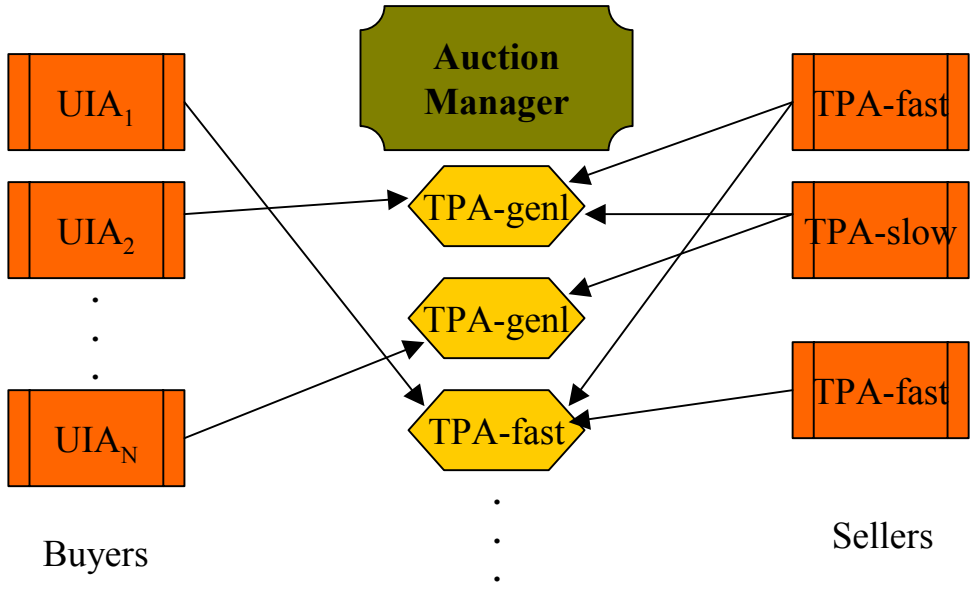
When is slow adaptation appropriate?

- some adaptations have **higher direct costs** (siting a nuclear plant)
  - transaction costs
  - coordination costs
- some environments are **more stable**:
  - transactions are routinized (cash withdrawals)
- some designs are more **tightly coupled**
  - other processes depend on them (e.g., law of contracts)
  - change takes time to propagate, and adjustment is costly: limit rate of change
- some design **errors** are more consequential

Roles for institutions in advanced commerce

- **bound the problem space** for exchange
  - technical standards
  - conventional product configurations
  - default rules (UCC)
  - enforcement mechanisms
- facilitate computational **feasibility**
  - reduce the complexity of the problem space
  - create block structure, shared memory

Example: UMDL society of agents



- Who makes decisions about:
  - starting/ending auctions?
  - participating in which auctions?
  - defining scope of auctions

Which decisions are endogenous, which are not?

Many TPAs, compete to buy auction resources from AMA and sell to UIAs?
AMA buys disk, bandwidth from...? (Competing AMAs or central planner?)
Disk and bandwidth brokers buy resources *they* need from...?
Does AMA enforce allocations?
Does AMA purchase enforcement inputs from police and court agents?

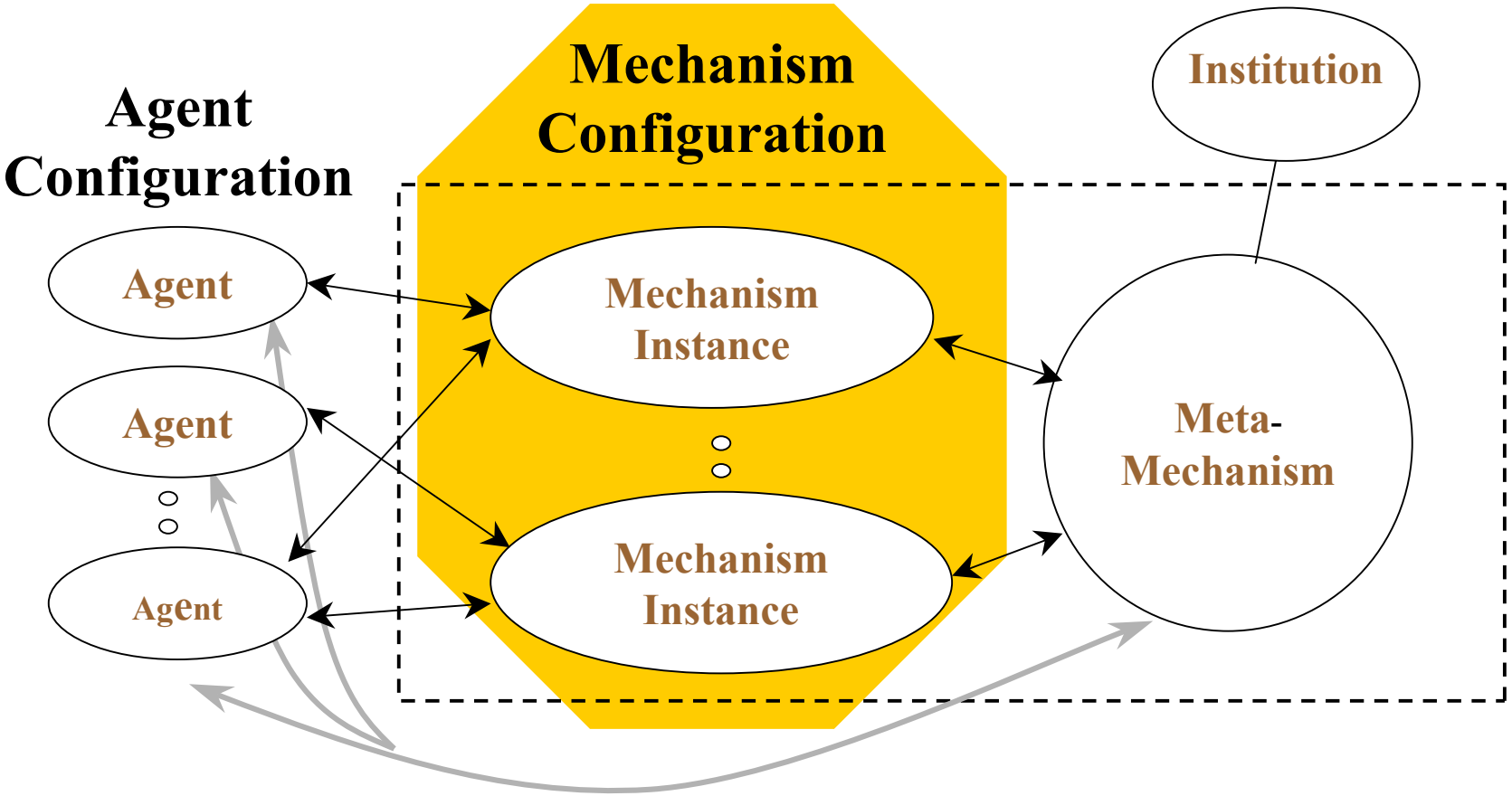
Institutions in multi-agent systems

- MAS need to find and settle issues that are of mutual concern to their agents
  - **which concerns** are specified?
  - **which mechanisms** are created to settle them?
- Mechanisms will generally be **approximate** and **temporary**
  - approximate due to design constraints and complexity
  - temporary because environment is changing and so quality of approximation tends to degrade

Endogenizing the institutions

- Good problem solving requires adaptive institutions
- How do we implement the mechanism design process **internally and dynamically** within an MAS?

MAS structure



Metamechanisms

- Agents **interact** through **instances** of mechanisms
- A metamechanism can **create and modify** mechanism instances
- These relationships can be defined **recursively** (metamechanisms take place within governance structures, which can reconfigure metamechanisms, &c.)

Summary

- A grand adventure…
  - With cheap silicon and sand we can solve previously intractable allocation problems
  - Vast opportunities for **frictionless** commerce, social problem solving
- …with grand challenges
  - Existing institutions evolved for expensive computation and communications
  - **How to design institutions and their evolution within** multi-agent systems?