Architecture for Ultra-Large-Scale (ULS) Systems

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Theories and constructs from the field of economics can endow the notion of architecture with new meaning and consequently offer structuring principles for Ultra-Large-Scale Systems.
What Is a Software Architecture?

“The software architecture of a program or computing system is the structure or structures of the system, which comprise the software elements, the externally visible properties of those elements, and the relationships among them.*”

• Architecture is an abstraction; it is not about the details, but …
• it expresses sufficient detail to support appropriate analyses …
• vis-à-vis important (quality attribute) requirements and …
• appropriately constrains more detailed design and implementation.

“… beyond certain complexity thresholds, a traditional centralized engineering perspective is no longer adequate nor can it be the primary means by which ultra-complex systems are made real. *”

“Like cities, ULS systems will not simply be bigger systems: they will be interdependent webs of software intensive systems, people, policies, cultures, and economics. *”

“Traditional economics views markets as simply the confluence of supply and demand. A new field of economics, known as ‘market design,’ recognizes that well-functioning markets depend on detailed rules. …”

- Market designers try to understand these differences and the rules and procedures that make various kinds of markets work well or badly.”

- Their aim is to know the workings and requirements of particular markets well enough to fix them when they’re broken or to build markets from scratch when they’re missing.* ”

Inspiration – Radio Spectrum Auction -1 *

Spectrum licenses (for use in wireless communication) were originally allocated on the basis of hearings by the FCC.

- procedure was time consuming; backlog developed
- switched to lotteries; winners could resell at high prices (winner of a license to run cellular telephones in Cape Cod sold it to Southwestern Bell for $41.5 million)

A previously unrecognized value proposition emerged

- generate revenue
- allocate efficiently
- generate public value
- encourage participate by small business, minorities, ...

Inspiration – Radio Spectrum Auction -2

“Elements” are individuals, organizations and resources
  - government
  - license acquirers; “properties” include:
    - private value for license based on competition situation, value placed on bundles of licenses based on competitive strategy and previously acquired licenses
    - financial status
    - minority status
    - competitive situation
  - game theorists (who want to put theories to practical use; the most recent Nobel Prize in economics was awarded for Mechanism Design)
  - resources
Inspiration – Radio Spectrum Auction -3

Problem type
• resource allocation
• resource to be allocated
  — intervals of radio spectrum
  — geographic regions

“Relations” are interaction protocols defined by mechanism, alternatives considered
• open vs. closed bidding
• first vs. second price auction
• sequential vs. simultaneous (allowing for license combinations)

Potential protocol “properties” (from game theory and mechanism design)
• Bayes-Nash equilibria
• incentive compatibility
Observations

Value proposition drives auction (and more generally) mechanism design

Value proposition and mechanism rules are at times learned and at times explicitly designed resulting in an interacting hierarchy of mechanisms *

- FCC policy
- Auction mechanism
- Cell phone system

Very different expertise is required for different levels of the hierarchy likely requiring different types of “architects” – the notion of a single central architecture team is “broken”.

*Aoki, M., Toward a Comparative Institutional Analysis, 2001.*
Observations

Economic theories
- exploit rational self-interest and scale – a natural fit for ULS systems
- inform system structure in much the same as quality attribute theories inform software architecture structure

Theories are not perfectly matched to the situations they model
- must rely on combination of theory, experiments, and experience *
- ULS system architecture must support this **

Theories from other diverse disciplines such as biology, organizational learning, and sociology are also likely to offer ULS system structuring principles.

** Conversation with Kevin Sullivan.
What Is a ULS System Architecture?

How about this?

The **architecture** of a ULS system is dynamic hierarchy / constellation of interacting system architectures, each with its own value propositions, element types (including individuals and organization) and associated properties (such as self-interest and private values), relations (such as those found in strategic games) and theories (such as game theory).

SEI ULS systems architecture research:
- Explore the nature of existing hierarchies / constellations
- Discover styles of ULS system architectures
- Continue exploring applicability of economic mechanisms
- Explore interaction between non-computational and computational mechanisms
- Explore institution design (Aoki)
- Explore theories from other disciplines