Market-Based Adaptive Architectures for Information Survivability



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Project Goal

- To show that *computational market mechanisms* can be designed to enhance the adaptivity, robustness, flexibility—and thus the *survivability*—of large-scale information systems

Making *distributed decision-support environments* survivable

- the system is fundamentally *distributed*
- system performance is measured by how well the information services contribute to *decision quality*
- survivability:
  - resources *will* be lost or degraded from time to time
  - the system should dynamically re-configure to provide the best mix of services after a resource loss

Characterizing a distributed decision-support environment

- resources
  - physical (RAM, wires, &c.)
  - services (computation, lookup, scheduling)
  - other (time, space, attention, expertise)
- agents
  - goal-directed
  - can reason about resources and actions
  - fundamental decision unit: human or artificial
- allocation mechanisms
  - assign resources to agents

Resource allocation

- every decision is really about *resource allocation*: choosing to employ a limited resource for one purpose in lieu of others
- focusing on resources:
  - performance under attack depends on the delivery of information resources to users
  - highlights *tradeoffs* among alternative activities
  - characterizing *multiagent interactions* in terms of resource transfers simplifies interfaces between agents

Resource allocation 2

- agents use resources to
  - consume
  - invest to produce new resources for later consumption or exchange
- state summary: *an allocation*
  - list of agents
  - their resource endowments
  - their commitments to engage in future resource exchanges

Resource allocation 3

- state transitions fully characterized by
  - resource transformations
  - exchanges
  - changes in future commitments
- state transitions are determined by a *mechanism*
  - we study a class of market mechanisms: agents submit messages to institutions which then specify the new allocation

Resource allocation 4

- markets allocation is defined by a set of *prices* such that . . .
  - . . . every agent may exchange as much as it desires at the going price
  - prices specify the terms of exchange: one unit of resource 3 may be exchanged for p_3 / p_7 units of resource 7

Resource allocation 5

- problem often decomposes
  - agents participate *externally* in a mechanism to determine their available resources
  - they *internally* apply these resources as they see fit
  - if there are no *externalities* then there are no interactions between agents in the resource application problem

Agents

- maximize a utility function subject to
  - constraints on resources (budget)
  - constraints on technology (production function)
- two major types
  - consumers
    - e.g., the human users of the system
    - consumer valuations ground the ultimate measure of system performance
  - producers
    - transform input resources (e.g., data, time, CPU cycles) into outputs

Agents 2

- each agent *makes decisions locally*
  - based only on personal knowledge base and prices announced by the mechanism
  - thus, *maximally modular*:
    - need no knowledge of others
    - good for survivability

Allocation Problems

- Goal: To construct a mechanism satisfying various desiderata subject to feasibility constraints
  - e.g., *Pareto efficiency*

Allocation 2

- market mechanisms often have nice properties: the two Fundamental Welfare Theorems
  - First: all competitive (price-taking) equilibria are Pareto efficient
  - Second: for a wide class of agent preferences and technologies, a competitive allocation can be designed to implement any Pareto efficient allocation

Allocation 3

- market prices direct the response to disruption
  - competitive equilibrium prices are the shadow values of the overall system optimization
  - they convey relative system scarcity of each resource
  - as a resource degrades or disappears, all of the shadow values adjust
  - therefore, no loss-of-service disaster “totally” disables the system; whatever resources remain will be efficiently allocated to accomplish the best possible outcome given the constraints

Networked Information System

- Two levels: network and applications
- Intimately linked:
  - applications need communications
  - therefore, survivability response requires joint examination

Example: Downed Link

- "reroute traffic to minimize the number of lost packets" may seem sensible
- but not if it results in delay or loss for some *critically* important material
- when not all services can be immediately restored
  - which services to restore?
  - to whom?
- should depend on the relative value of the services *to the different application streams, at the time of the attack*: must model both the network and application services

Network level

- to fulfill Quality of Service (QoS) requirements, can reserve resources in 3 dimensions
  - type and amount of resources required
  - time between reservation and use of resources, and
  - strictness of the reservation guarantee
- agents express intensity of preferences for resource bundles through bidding

Network level 2

- three reservation types based on the time between reservation and use of resources:
  - advance,
  - immediate, and
  - in situ
- reservations may also differ in the strictness of their contractual bounds

Applications level

- processing, interpretation, selection, or other value-added transformations applied to resources from other applications, the network layer, or the external world

Applications level 2

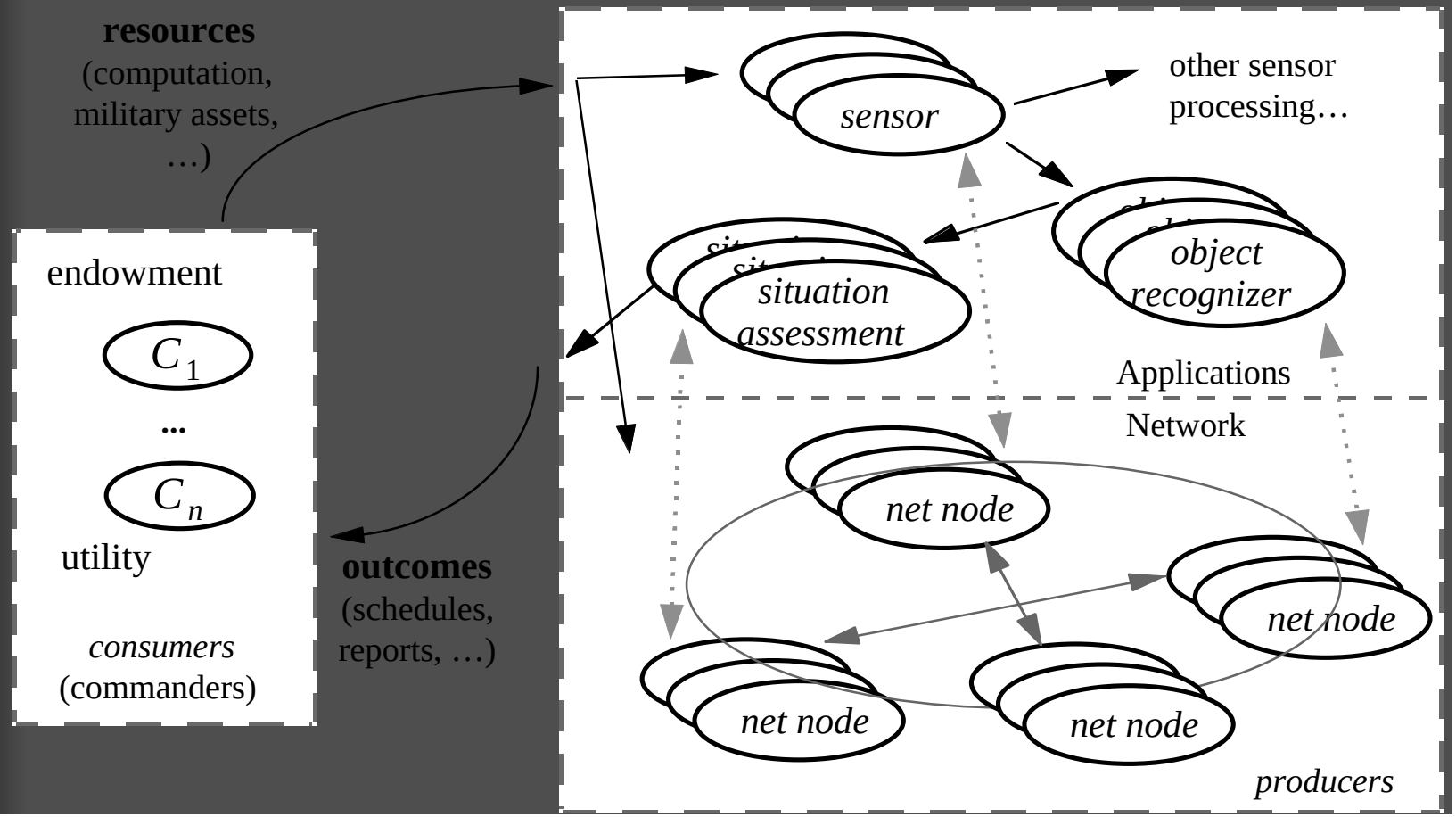
- example: directory service requires . . .
  - network services for delivery of queries and responses
  - directory records and updates from other information applications, and
  - authentication and authorization services

Applications level 3

- in practice, many different applications, requiring different mix of resources
  - market-based approach well-suited to coordinate responses across the many different applications and users that rely on the disrupted service

Example system

- two-layer model: network and applications



Example cont.

- Problem: deploy the available resources to sensing, processing, and communications activities so as to maximize the value of the resulting information to the commanders
- assignments of resources to particular activities is done by individual agents
  - each resource is represented by an agent
  - each agent seeks own self-interest

Example cont.: Disruption Scenario

- object recognition service requires both applications and network services:
  - packet-delivery network service
  - image data from sensor agents, and
  - authorization and authentication services
  - supercomputer computation

Example cont.: Consequences

- suppose attack disables supercomputer site, some network links and some security servers
- immediate consequences:
  - net capacity temporarily insufficient; congestion exacerbated by extra disaster response communications demand
  - sensing and security capacity is insufficient

Example cont.: Disaster Response

- urgent object recognition needs bid more for resources
  - less urgent owners of network resources offer them for sale as cost of holding on goes up
  - likewise, prices for security and image data increase, so those with most urgent needs get priority

Example cont: Response 2

- increased input costs raise price of recognition services to end users
  - less urgent recognition consumers reduce demands so the more scarce resources are allocated to those with the highest value needs
- prices rise and demands decrease until only a feasible number of service requests are made, and those by the highest value users

Example cont: Response 3

- resources are dynamically reconfigured to those activities that most value them, so that the diminished system provides a set of surviving services that are best from the viewpoint of the commanders

Some research issues

- intertemporal resource allocation: how many futures markets, how many time periods, how many goods?
- risk allocation: uncertainty is fundamental during disruption: need instruments to insure and hedge

Research issues 2

- strategic behavior: optimality results assume agents act competitively, as price-takers. Some agents may have market power to advance their individual goals, sometimes at the expense of overall goals, by acting strategically

Research issues 3

- externalities: physical laws, incomplete property rights and incomplete markets can cause agents to care about other agents' allocations -- externalities complicate the search for efficient mechanisms
- nonrival resources: many information goods are nonrivalrous -- the material balance constraint is inappropriate so the allocation mechanism needs modification

Architectural components to develop

- agents
- resources
- negotiation protocol
- allocation mechanism
- banking and security services, and enforcement

Michigan AuctionBot

