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A Program of Work for Understanding Emergent Behavior in Global Grid Systems

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Outline

- What are emergent behaviors?
- Why are emergent behaviors likely in global grids?
- Can emergent behaviors be elicited or controlled?
- How are NIST researchers investigating these questions?
- Case study: denial-of-service (DoS) attack on simulated grid

What are emergent behaviors?

Emergent behaviors are
coherent system-wide properties
that cannot be deduced directly from
analyzing behavior of individual components

Emergent behaviors typically arise in
dynamic open complex adaptive systems,
where system-wide behavior derives from
self-organizing interactions among myriad components

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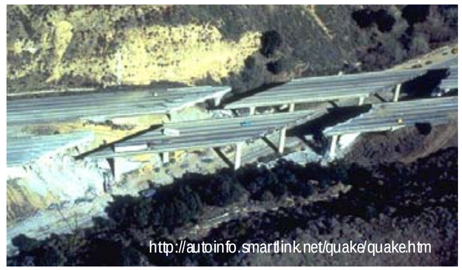
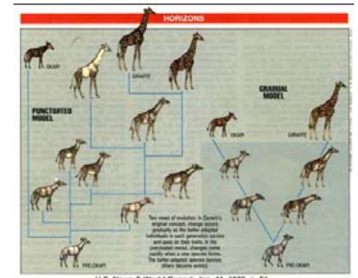
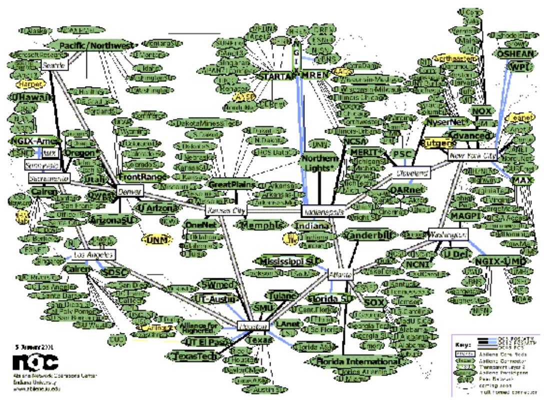
Some Dynamic Open Complex Adaptive Systems




U.S. News & World Report, Jan. 11, 1988, p. 51.


http://www.ics.uci.edu/relations/develop/rs2001/teitelbaum/sld012.htm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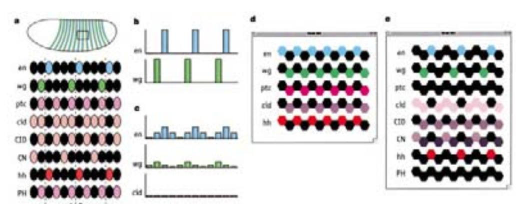
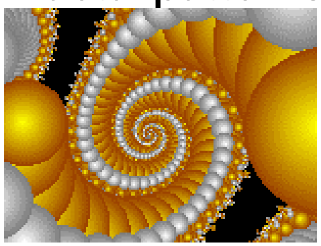

©http://emergent.brynmawr.edu 2003

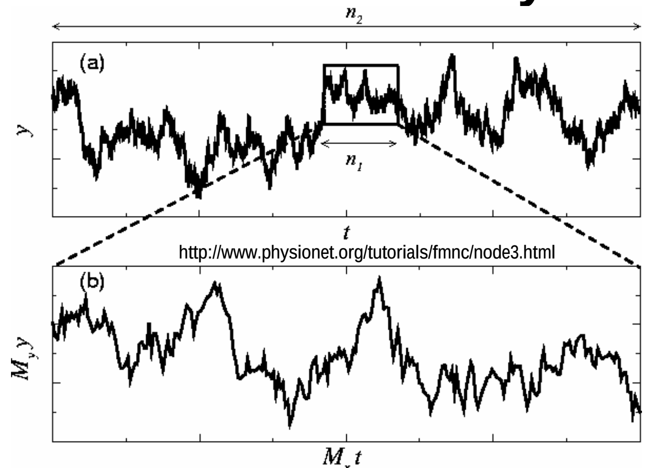
How might a complex system be detected?

fractal patterns



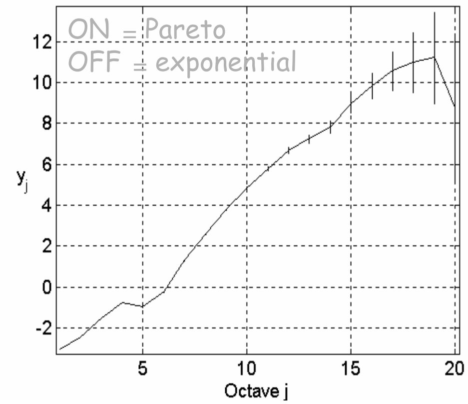
http://www.mbfractals.com/usergal/dougowen.html

self-similarity

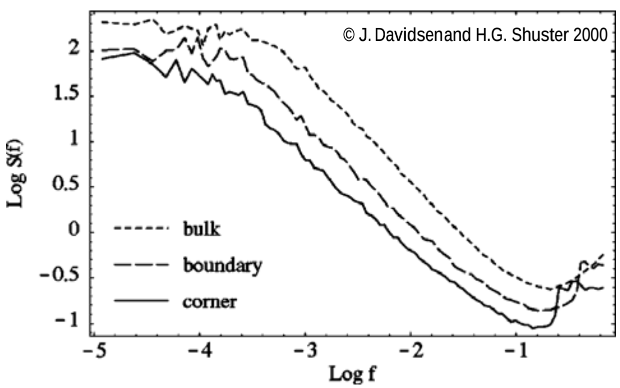


http://www.physionet.org/tutorials/fmnc/node3.html

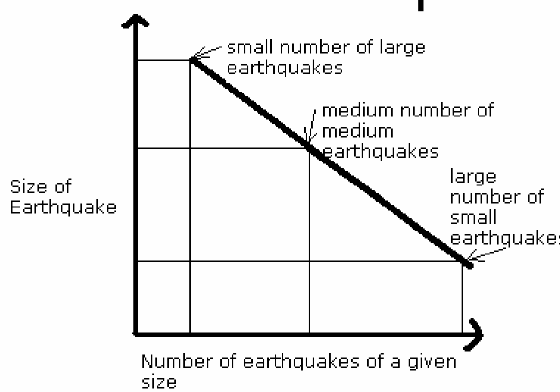
linear wavelets



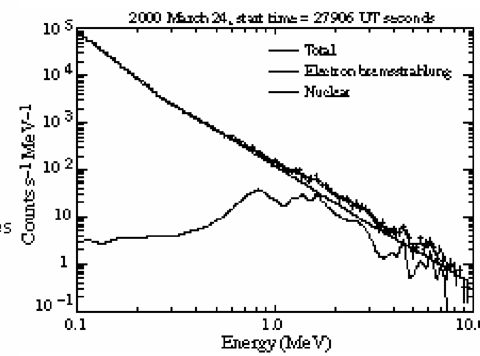
1/f noise



power laws



http://complexity. orcon.net.nz/powerlaw.html



http://heseweb.nrl.navy.mil/gamma/solarflare/24mar00.htm

Other ideas include: decrease in entropy or changes in statistical complexity

What characteristics might lead to a complex system?

- System Scale – order emerges from many interactions over space and time
- Communications Locality – inability to know global state
- Element Simplicity – inability to process all possible states
- Feedback – elements can sense environment and estimate global state
- Element Autonomy – each element can vary its behavior based on feedback

Why are emergent behaviors likely in global grids?

- Scale: large number of clients and services interacting via indirect coupling arising through use of shared resources
- Communications Locality: clients cannot obtain complete and timely state of all resources – decisions must be made on partial information
- Element Simplicity: clients possess limited processing power – decisions must be made with heuristics
- Feedback: clients learn fate of resource requests and adapt subsequent requests based on updated information
- Element Autonomy: clients decide how to proceed with no central control or direction

Can emergent behaviors be elicited or controlled?

Remains an open research question, for example:

– NASA exploring emergent programming to increase adaptability and survivability of future spacecraft (see Kenneth N. Lodding, "Hitchhikers Guide to Biomorphic Software", *ACM Queue* vol. 2, no. 4)

– MIT exploring amorphous computing where systems structure and specialize themselves from a common set of components (http://www.swiss.csail.mit.edu/projects/amorphous)

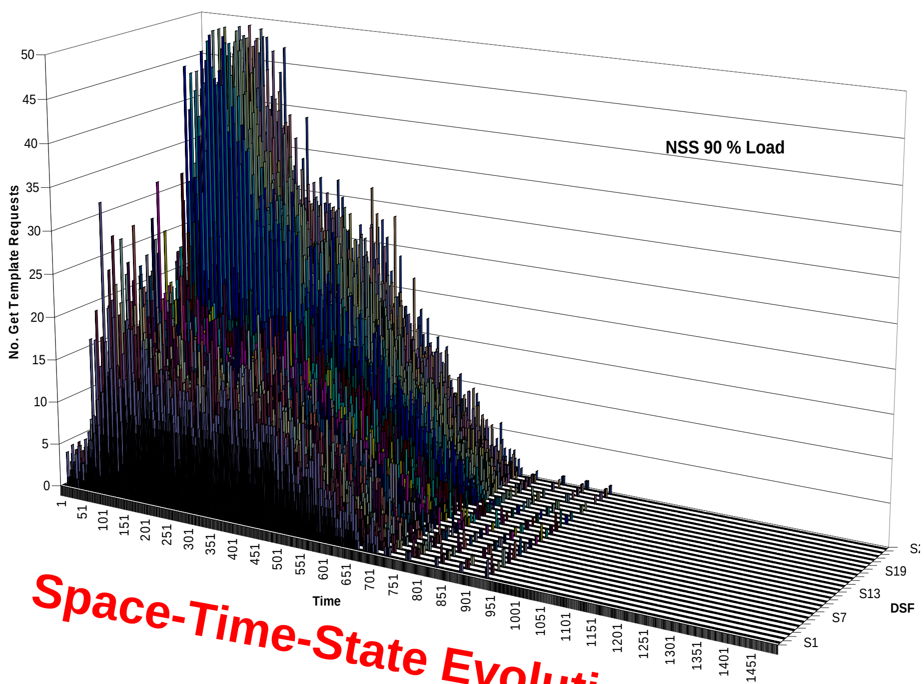
– Radhika Nagpal (Harvard) studying how to engineer and understand self-organizing systems (http://www.eecs.harvard.edu/~rad)

– Several researchers exploring application of economic mechanisms, such as markets, auctions, and present-value calculations, as means to elicit effective behavior in distributed systems

How are NIST researchers investigating these questions?

Goals

- Understand self-organizing properties in service-oriented architectures (SOA)
- Investigate mechanisms to shape emergent behavior in SOA
- Improve related consortia specifications w.r.t. robustness, reliability, performance



Space-Time-State Evolution

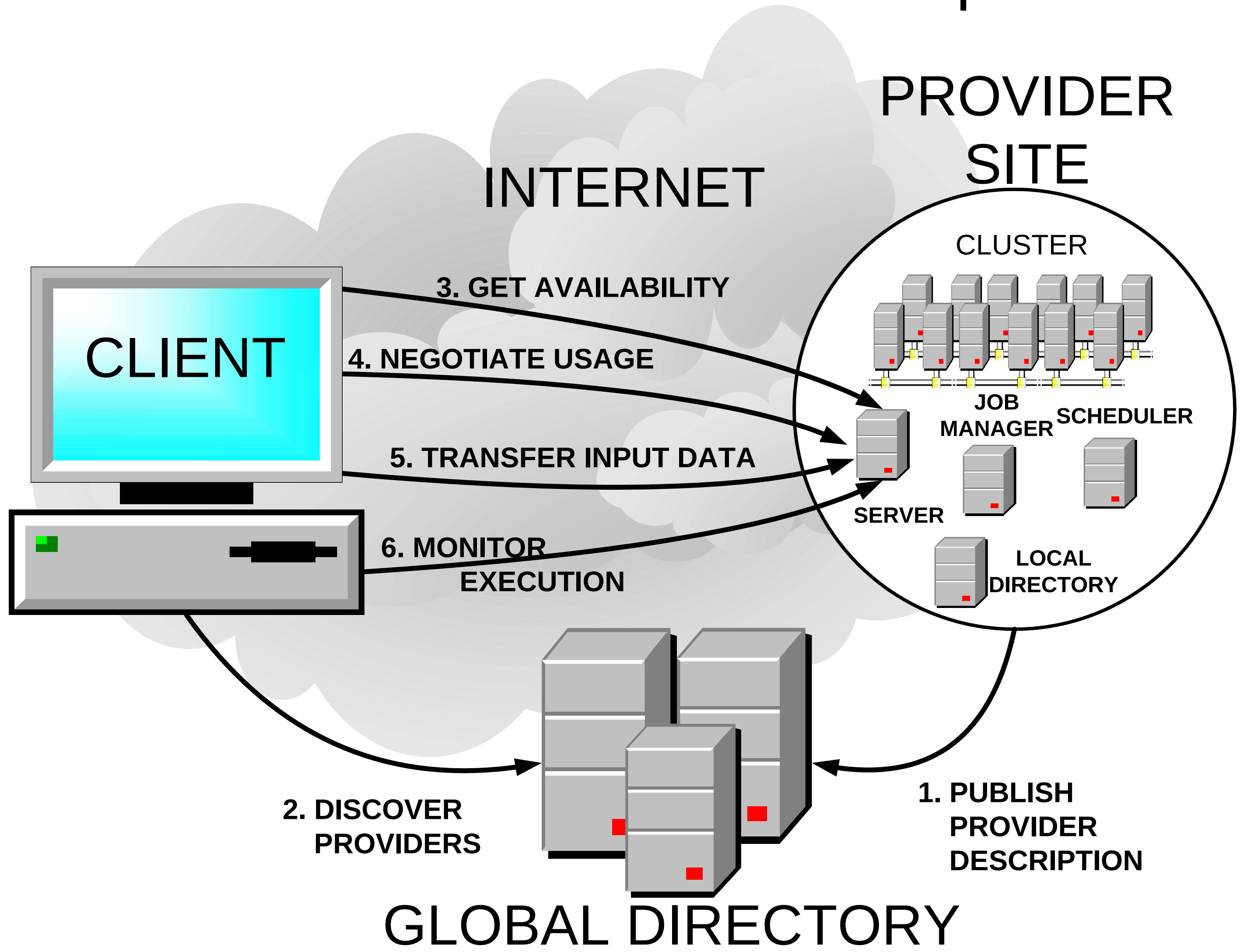
Technical Approach

- Apply modeling and analysis techniques from the physical sciences
- Exploit exploratory data analysis and visualization methods
- Investigate control techniques from biology and economics

Project Phases

- Micro-model: 10^3 to 10^4 elements based on selected industry specs
- Macro-model: 10^4 to 10^6 agent-based model containing selected abstractions validated against micro-model

Architecture of Global Compute Grid



Micro-model conception

Layered Component Architecture

- Network Layer: sites located in (*x,y,z*)-space used to compute distance in hops and simulate transmission delays;TCP-like simulated transport protocol; nodes model CPU delays, buffer & port capacity
- Basic Web Services: WS- Addressing and Messaging
- WSRF: WS- Resource Property, Lifetime, Notification, Topics, Service Group
- Grid Services: MDS v4, WS-Agreement, and DRMAA

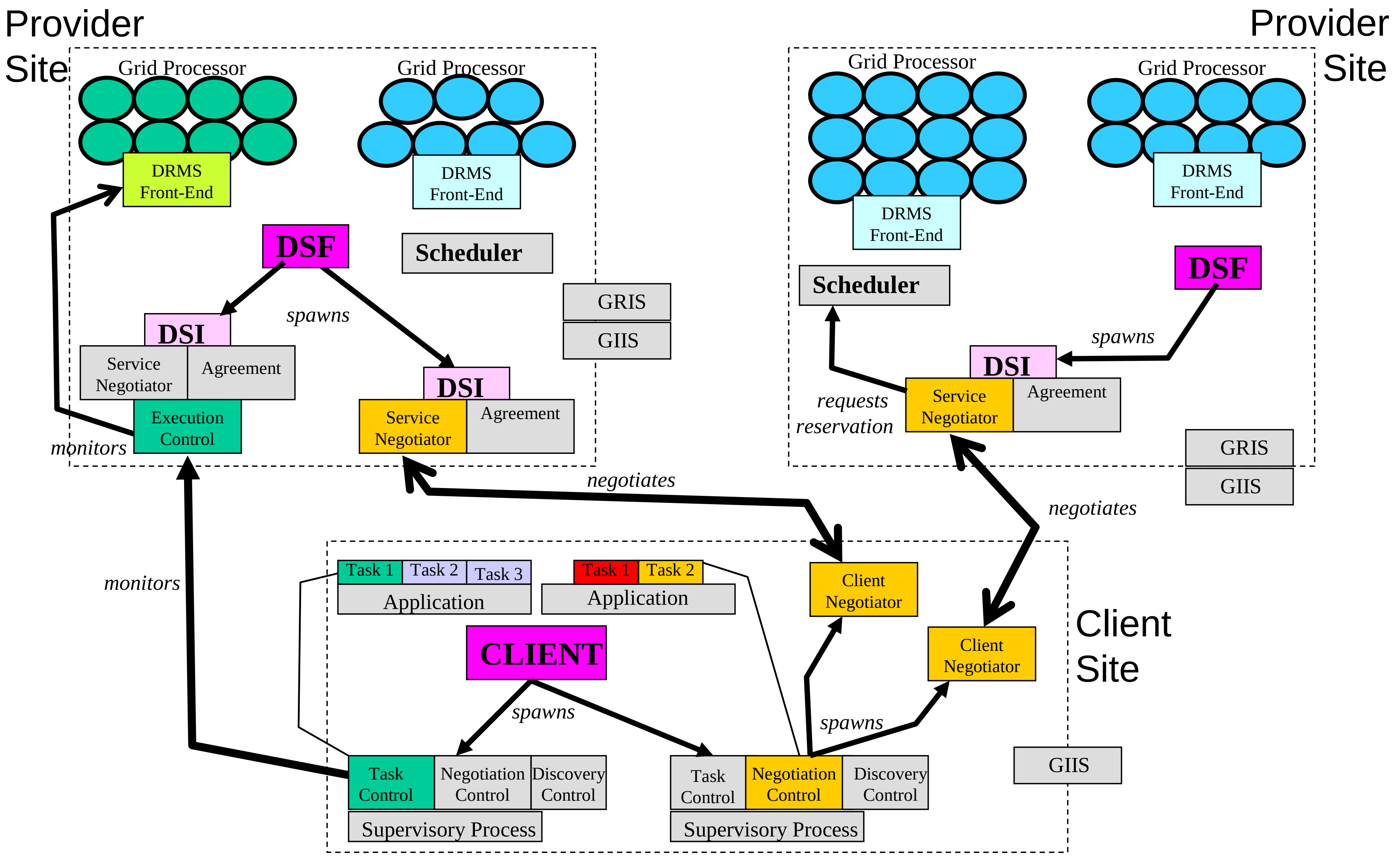
Major Grid Entities

- Service Providers: negotiate, schedule, execute, and monitor client tasks on vector or cluster computers maintained at a related site
- Clients: discover providers, rank discoveries by earliest availability, seek agreements, submit & monitor jobs

Client Grid Applications

- Application types: workflows of *n* sequential tasks, each with parallelizable sub-computations – dependent tasks may not start until preceding task completes
- Tasks: types defined by tuple (required code, task parallelism, compute cycles) and matched to processor component with suitable code and parallelism
- Workload: represented as a percentage of system capacity – regulated by assignment of applications to clients

Schematic showing operation of simulated grid



Case Study: DoS Attack on Simulated Grid

- Deploy simulated topology: 200 nodes covering 30 provider sites and 12 clients, where each client uses one of two negotiation strategies
- Negotiation strategies: serial reservation requests (SRR) or concurrent reservation requests (CRR)
- Run baseline: 50% workload for 200,000 simulated seconds and measure the distribution of job completion times
- Repeat run: inject service-provider spoofing with probability 50%, effectively reduces system capacity by half on average
- Repeat run: identical spoofing but introduce a strategy to resist spoofing: identify spoofers and do not repeat interactions with them

Three Questions of Interest

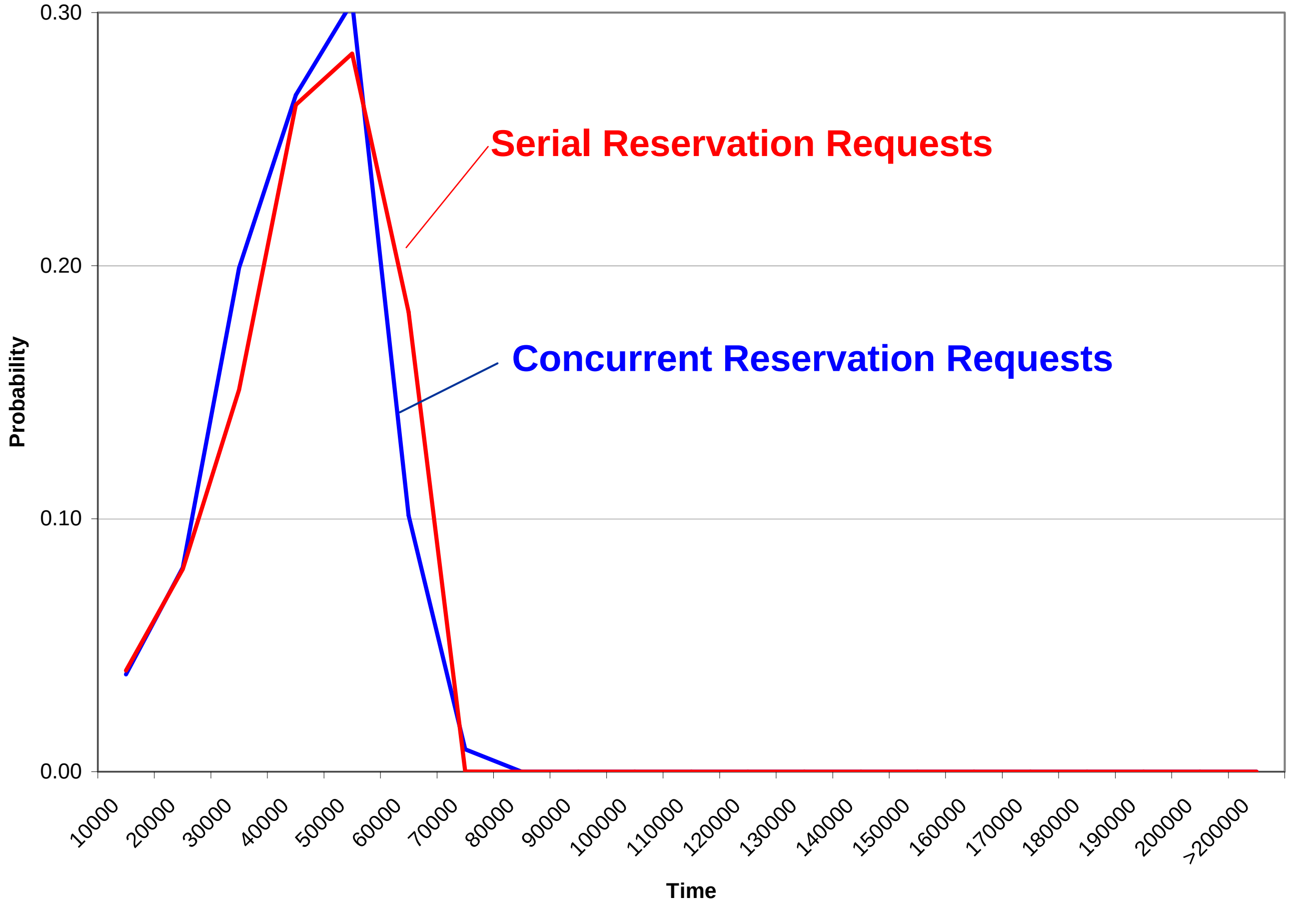
1. Which negotiation strategy is more effective under normal conditions?
2. Does the outcome change under attack?
3. Does the outcome change when resisting attack?

Bottom Line

1. CRR performs slightly better than SRR under normal conditions
2. CRR performs significantly better than SRR under attack scenario
3. Surprise: both CRR and SRR perform worse when resisting attack and the performance of CRR deteriorates more than SRR

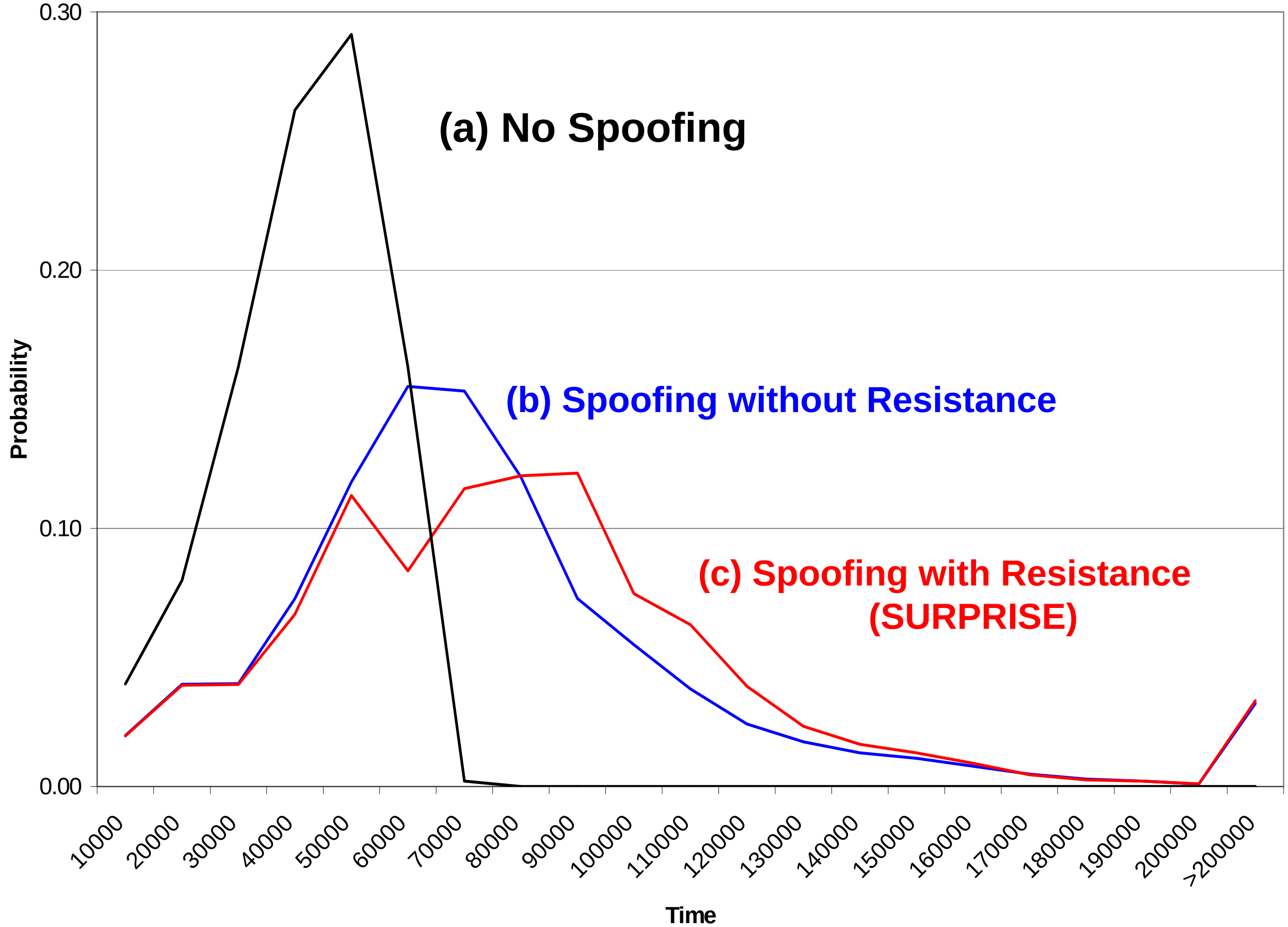
The surprise arises because scheduling and execution of jobs in the global grid is an emergent behavior arising from a self-organizing property of distributed resource-management algorithms

Serial Reservation Requests (SRR) vs. Concurrent Reservation Requests (CRR) with No Spoofing



Comparative distribution of application completion times for two negotiation strategies (over 200+ repetitions)

Performance Degradation caused by Spoofing in Grid where 50% clients use SRR and 50% use CRR



Comparative distribution of application completion times: (a) No Spoofing, (b) Spoofing without Resistance, and (c) Spoofing with Resistance (200+ repetitions)

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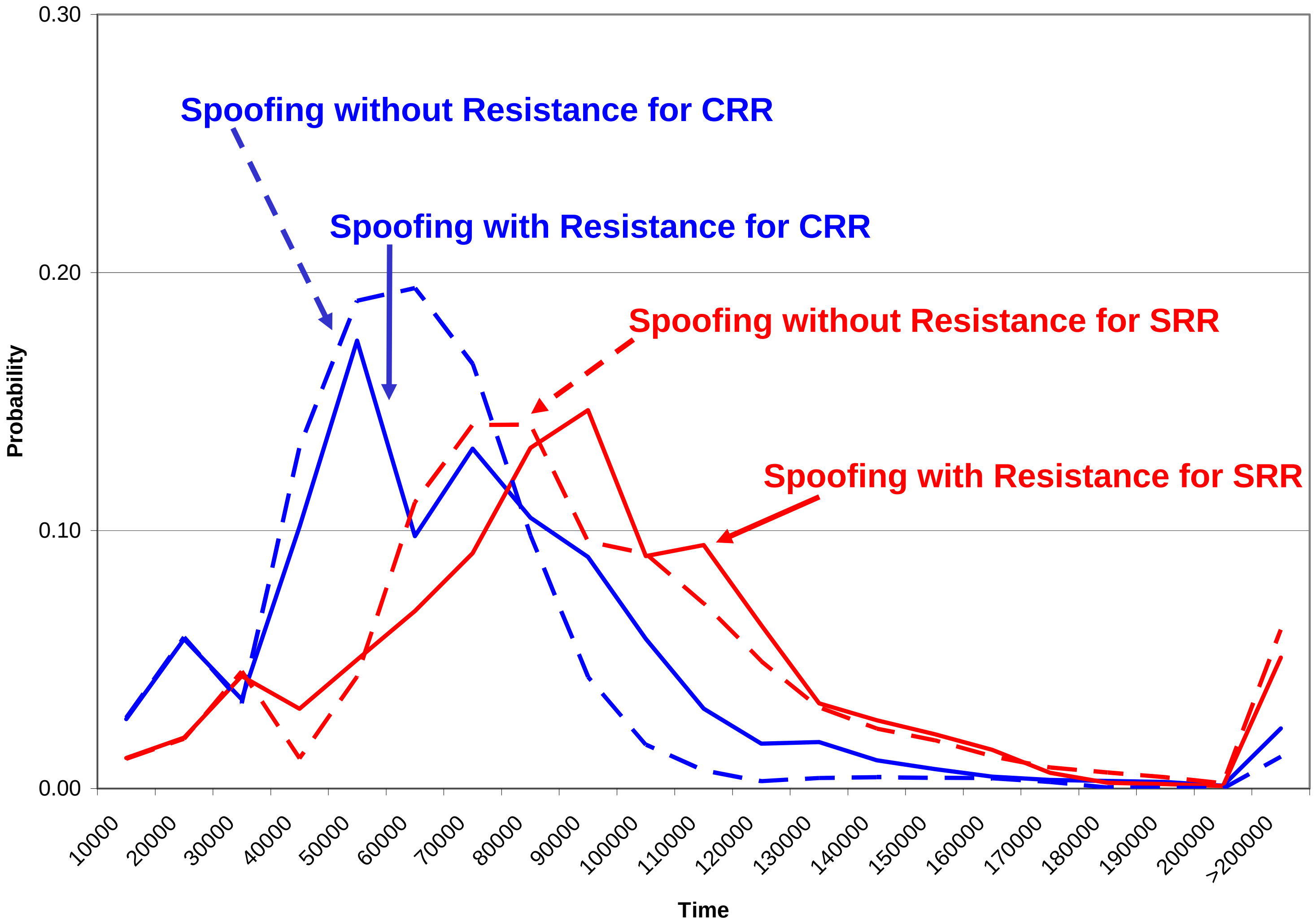
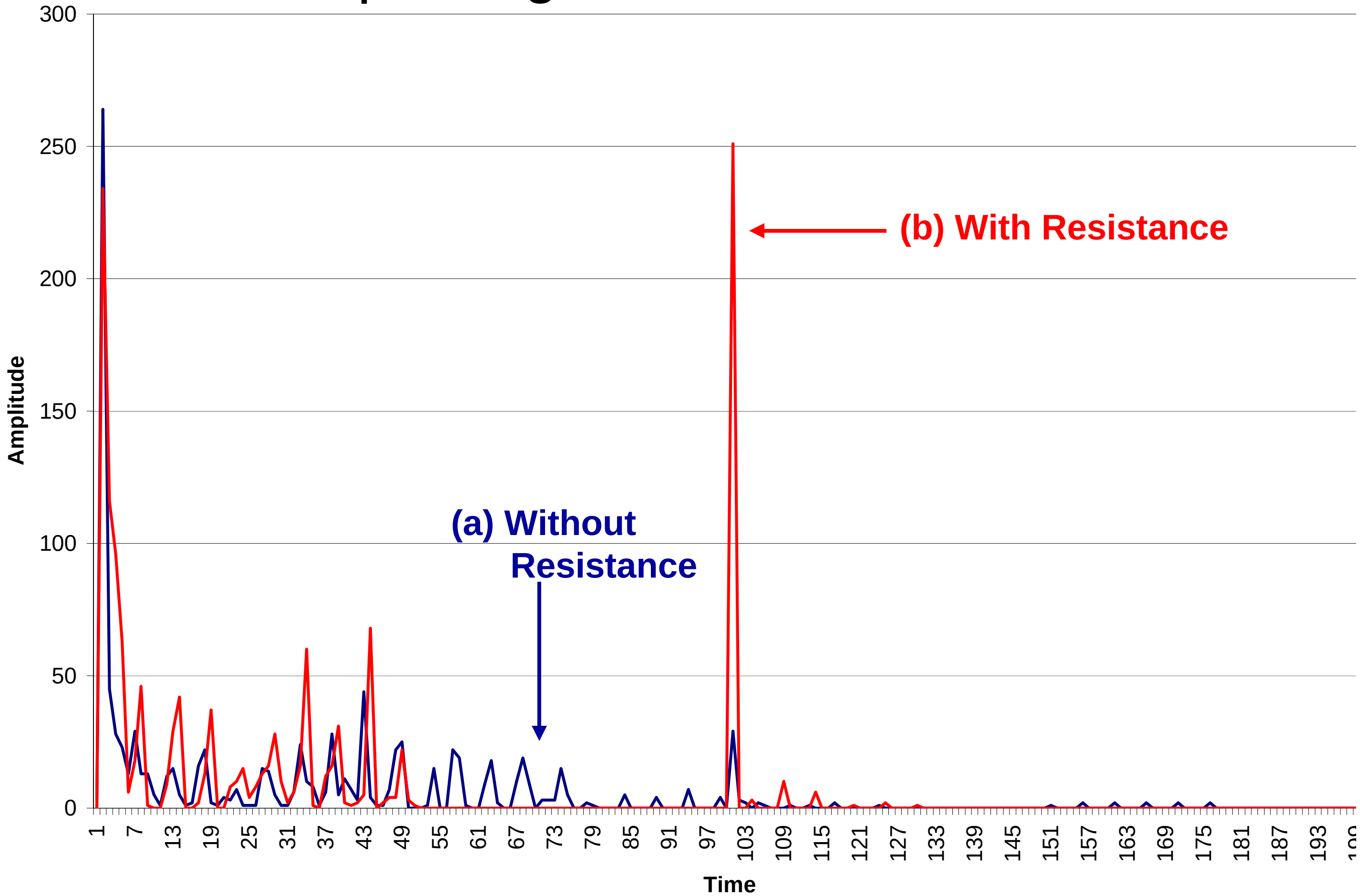
Decomposing performance degradation caused by spoofing

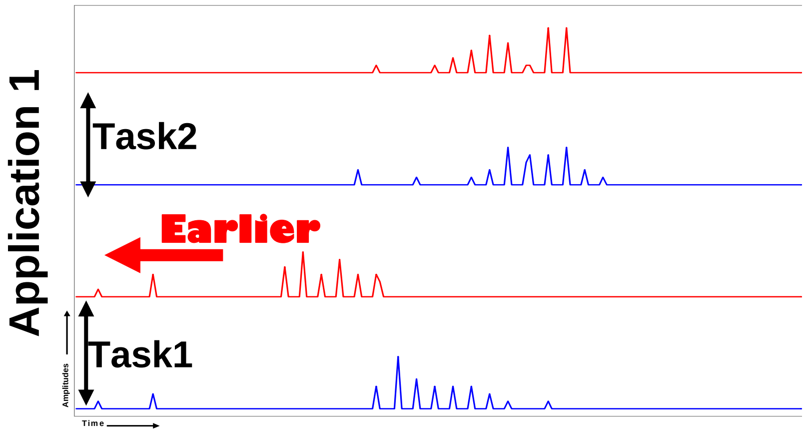


Aggregate Reservations Created over Time under Spoofing with and without Resistance

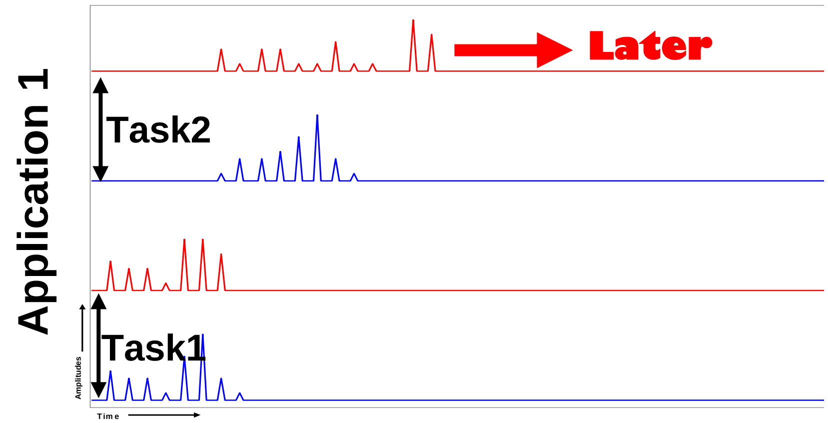


Two Time Series: (a) Reservations Created without Resistance and (b) Reservations Created with Resistance – 50% clients SRR and 50% CRR

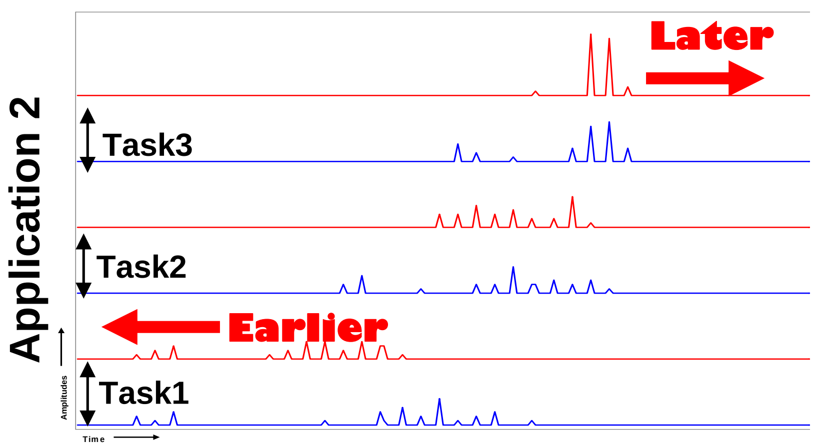
Time Series for Application/Task Completions: Two Application Types without Resistance (lower blue) vs. with Resistance (upper red)

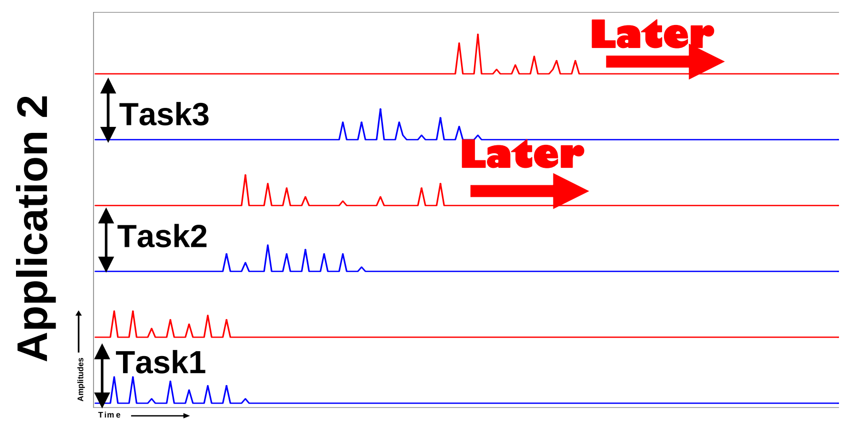


Serial Reservation Requests (SRR)



Concurrent Reservation Requests (CRR)





Conclusions

- Global Grids will be dynamic open complex adaptive systems with self-organizing properties leading to emergent behaviors

- Changes made to behavior in individual components could have pervasive and unexpected effects on global behavior

- We need to develop a science of complex information systems in order to predict and control macroscopic behavior