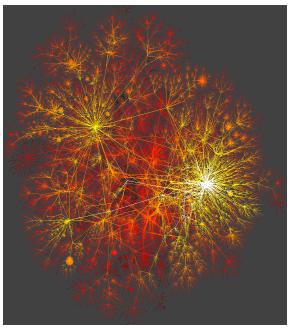
CS514: Intermediate Course in Computer Systems

Lecture 31: April 7, 2003
Astrolabe

The Internet



Source: Burch and Cheswick

Massive scale.
Constant flux

Demand for more "autonomic", intelligent behavior

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- Human beings constantly adapt as their environment changes
  - You bike up hill… start to breath hard and sweat. At the top, cool off and catch your breath
  - It gets cold so you put on a sweater
- But computer systems tend to be rigid and easily disabled by minor events

Typical examples

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- IBM finds that many Web Services systems are perceived as unreliable
  - End-user gets erratic response time
  - Client could be directed to the wrong server site
- But the Web Sphere software isn't at fault!
  - Usually these problems arise from other systems to which WS is connected
  - A snarl of spaghetti sits behind the front end

A tale of woe

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- Human operators lack tools to see state of system
  - Can't easily figure out what may be going wrong
- In fact operators cause as much as 70% of all Web-related downtime!
- And they directly trigger 35% of crashes

Sample tale of woe

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- Delta Airlines maintains the "Delta Nerve Center" in Atlanta
  - It has an old transactional mainframe for most operations
  - Connected to this are a dozen newer relational database applications on clusters
  - These talk to ~250,000 client systems using a publish-subscribe system

Delta Architecture

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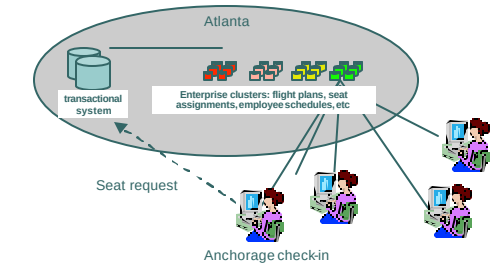

Anchorage goes down

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- Problem starts in Atlanta
  - System operator needs to move a key subsystem from computer A to B
  - But the DNS is slow to propagate the change (maybe 48 to 72 hours)
- Anchorage still trying to talk to A
  - So a technician fixes the problem by typing in the IP address of B
  - Gets hired by United with a hefty raise

Delta Architecture

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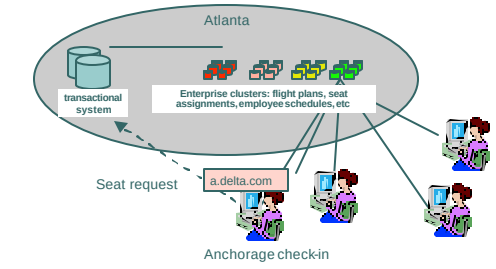

Delta Architecture

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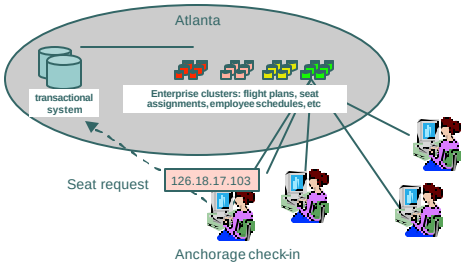

Delta Architecture

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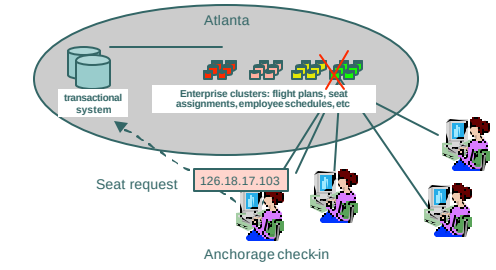

Six months later…

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- Time goes by and now we need to move that service again Anchorage crashes again…
  - But this time nobody can figure out why!
  - Hunting for references to the service or even to B won't help
  - Need to realize that the actual IP address of B is wired into the application now
  - Nobody remembers what the technician did or why he did it!

Homeland Defense and Military Data Mining

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- Issue is even worse for a new generation of "smart" data mining applications
- Their role is to look for something on behalf of the good guys
  - Look for images of tall thin guys with long white beards on horseback

The Dilemma of the Intelligent Application

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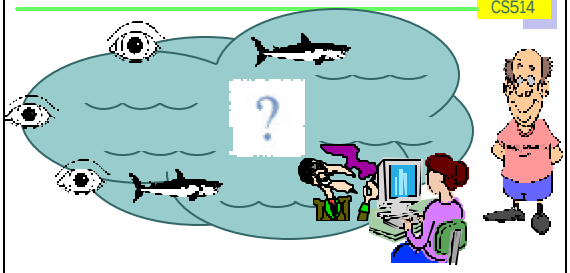

Intelligent application is separated from sensors by the network It lives in a sea of shifting state, changing conditions and threats…

Two options

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- We could ship all the data to the analyst's workstation
  - E.g. ship every image, in real-time
  - If N machines gather I images per second, and we have B bytes per image, the load on the center system grows with N*I*B. With A analysts the load on the network grows as N*I*B*A
- Not very practical.

Two options

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- Or, we could ship the work to the remote sensor systems
  - They do all the work "out there", so each just searches the images it is capturing
  - Load is thus quite low
- But how could we build such a system?

Sentient Distributed Systems

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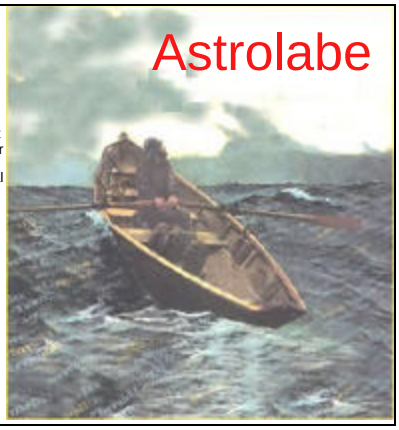
- Can we build a new generation of smart middleware in support of these new intelligent systems?
  - Middleware that *perceives* the state of the network
  - It can *represent this knowledge* in a form smart applications can exploit
  - Although built from large numbers of rather dumb components the *emergent behavior is intelligent.* These applications are more robust, more secure, more responsive than any individual component
  - When something unexpected occurs, they can *diagnose the problem* and trigger a *coordinated distributed response*
  - They *repair themselves* after damage

Astrolabe

- Intended as help for applications adrift in a sea of information
- Structure emerges from a randomized peer-to-peer protocol
- This approach is robust and scalable even under extreme stress that cripples more traditional approaches

Developed at Cornell

- By Robbert van Renesse, with many others helping…
- Just an example of the kind of solutions we need
- Astrolabe is a form of knowledge representation for sentient networks



Astrolabe builds a hierarchy using a P2P protocol that "assembles the puzzle" without any servers

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Dynamically changing query output is visible system-wide

SQL query "summarizes" data

Astrolabe in a single domain

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- Each node owns a single tuple, like the management information base (MIB)
- Nodes discover one-another through a simple broadcast scheme ("anyone out there?") and gossip about membership
  - Nodes also keep replicas of one-another's rows
  - Periodically (uniformly at random) merge your state with some else…

State Merge: Core of Astrolabe epidemic

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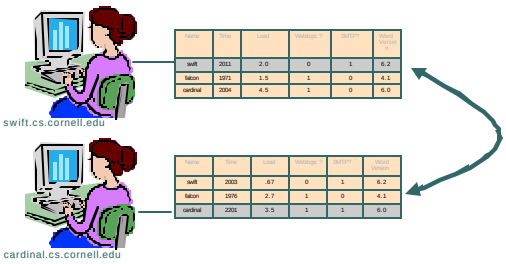

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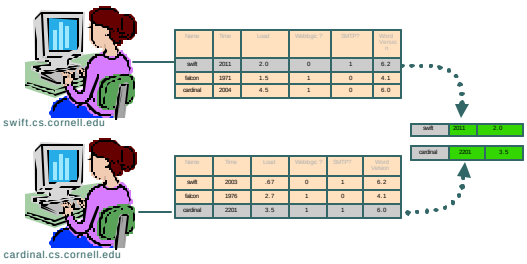

State Merge: Core of Astrolabe epidemic

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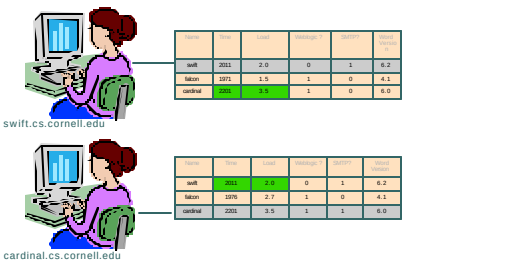

Observations

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- Merge protocol has constant cost
  - One message sent, received (on avg) per unit time.
  - The data changes slowly, so no need to run it quickly – we usually run it every five seconds or so
  - Information spreads in O(log N) time
- But this assumes bounded region size
  - In Astrolabe, we limit them to 50-100 rows

Big system will have many regions

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- Astrolabe usually configured by a manager who places each node in some region, but we are also playing with ways to discover structure automatically
  - For example could use Paul's ID Maps or the new CMU GNP concept
- A big system could have *many* regions
  - Looks like a pile of spreadsheets
  - A node only replicates data from its neighbors within its own region

Scaling up… and up…

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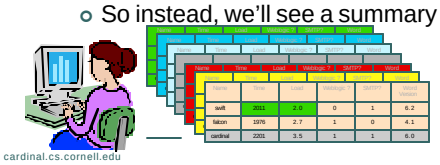
- With a stack of domains, we don't want every system to "see" every domain
  - Cost would be huge
- So instead, we'll see a summary



Astrolabe builds a hierarchy using a P2P protocol that "assembles the puzzle" without any servers

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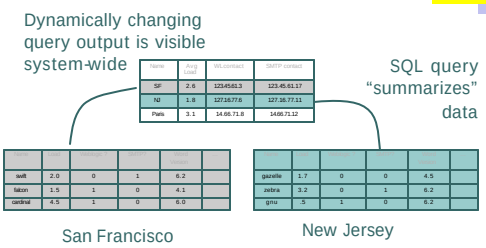

Large scale: "fake" regions

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- These are
  - Computed by queries that summarize a whole region as a single row
  - Gossiped in a read-only manner within a leaf region
- But who runs the gossip?
  - Each region elects "k" members to run gossip at the next level up.
  - Can play with selection criteria and "k"

Hierarchy is virtual… data is replicated

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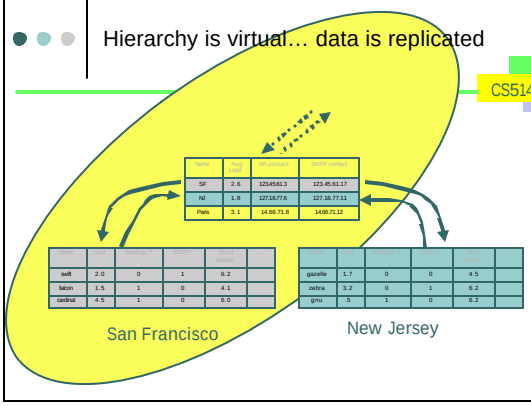

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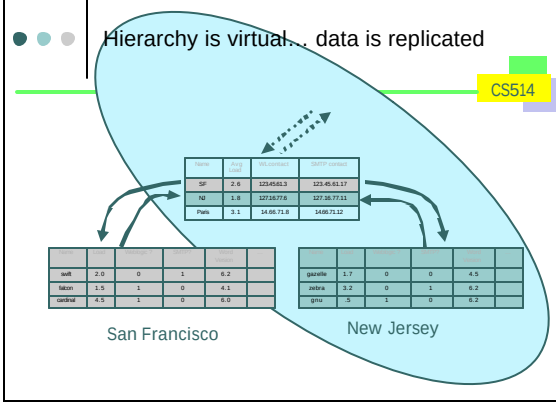

Worst case load?

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- A small number of nodes end up participating in $O(\log_{fanout} N)$ epidemics
  - Here the fanout is something like 50
  - In each epidemic, a message is sent and received roughly every 5 seconds
- We limit message size so even during periods of turbulence, no message can become huge.
  - Instead, data would just propagate slowly
  - Haven't really looked hard at this case

What makes Astrolabe a good fit

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- Notice how hierarchical database abstraction "emerges" without ever being physically represented on any single machine
  - Moreover, this abstraction is very robust
  - It scales well… localized disruptions won't disrupt the system state… consistent in eyes of varied beholders
  - Yet individual participant runs a nearly trivial peer-to-peer protocol
- Supports distributed data aggregation, data mining. Adaptive and self-repairing…

Data Mining

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- In client-server systems we usually
  - Collect the data at the server
  - Send queries to it
- With Astrolabe
  - Send query (and CFC) to edge nodes
  - They pull in desired data and query it
  - User sees a sort of materialized result

Pros and Cons

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- Pros:
  - As you look "up" the hierarchy the answer you see can differ for different users ("where can I get some gas?")
  - Parallelism makes search fast
- Cons:
  - Need to have agreement on what to put into the aggregations
  - Everyone sees the same hierarchy

Other such abstractions

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- Scalable probabilistically reliable multicast based on P2P (peer-to-peer) epidemics
- Some of the work on P2P indexing structures and file storage
- Stoica's new ideas for a P2P Internet Indirection Infrastrastructure

Solutions that share properties

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- Scalable
- Robust against localized disruption
- Have emergent behavior we can reason about, exploit in the application layer
- Think of the way a hive of insects organizes itself or reacts to stimuli. There are many similarities

Revisit our goals

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- Are these potential components for sentient systems?
  - Middleware that *perceives* the state of the network
  - It *represent this knowledge* in a form smart applications can exploit
  - Although built from large numbers of rather dumb components the *emergent behavior is intelligent.* These applications are more robust, more secure, more responsive than any individual component
  - When something unexpected occurs, they can *diagnose the problem* and trigger a *coordinated distributed response*
  - They *repair themselves* after damage
- We seem to have the basis from which to work!

Brings us full circle

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- Our goal should be a new form of very stable "sentient middleware"
- Have we accomplished this goal?
  - Probabilistically reliable, scalable primitives
  - They solve many problems
  - Gaining much attention now from industry, academic research community
- Fundamental issue is skepticism about peer-to-peer as a computing model

Conclusions?

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- We're at the verge of a breakthrough – networks that behave like sentient infrastructure on behalf of smart applications
- Could open the door to big advances
- But industry has yet to deploy these ideas and may think about them for a long time before doing so