CS162
Operating Systems and Systems Programming
Lecture 27

Peer-to-peer Systems and Other Topics

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Goals for Today

- A couple of requested topics
  - Windows vs. Linux
  - Trusted Computing
- Peer-to-Peer Systems
  - OceanStore

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne

Requests for Final topics

- Some topics people requested:
  - More about device drivers
  - Xbox/Playstation/gamecube/etc operating systems
  - Windows vs Linux
  - Trusted computing platforms
- About Device Drivers
  - Well, very complex topic.
  - Documentation associated with various operating systems
    - » Many similarities, many differences
  - Good place to start:
    - » Chapter 6 of "The design and Implementation of the 4.4 BSD Operating System" (on reserve for this class)
- Xbox vs Playstation etc
  - Well, most of these are custom OSs.
    - » Original Xbox ran modified version of Window 2000
    - » New Xbox 360 rumored to run modified version of original Xbox OS (i.e. a modified^2 version of Windows 2000)
  - Most important property: Real Time scheduling
    - » Ability to meet scheduling deadlines

Windows vs Linux

- Windows came from personal computer domain
  - Add-on to IBM PC providing a windowing user interface
    - » Became "good at" doing graphical interfaces
  - Didn't have protection until Windows NT
    - » Multiple users supported (starting with Window NT), but can't necessarily have multiple GUIs running at same time
  - Product differentiation model:
    - » Purchase separate products to get email, web servers, file servers, compilers, debuggers…
- Linux came from long line of UNIX Mainframe OSs
  - Targeted at high-performance computation and I/O
    - » High performance servers
    - » GUI historically lacking compared to Windows
  - Protection model from beginning
    - » Multiple users supported at core of OS
  - Full function Mainframe OS: email, web servers, file servers, ftp servers, compilers, debuggers, etc.

Windows vs Linux

- Internal Structure is different
  - Windows XP evolved from NT which was a microkernel
    - » Core "executive" runs in protected mode
    - » Many services run in user mode (Although Windowing runs inside kernel for performance)
    - » Object-oriented design: communication by passing objects
    - » Event registration model: many subsystems can ask for callbacks when events happen
    - » Loadable modules for device drivers and system extension
  - Linux Evolved from monolithic kernel
    - » Many portions of kernel operate in same address space
    - » Loadable modules for device drivers and system extension
    - » Fewer layers ⇒ higher performance
- Source Code development model
  - Windows: closed code development
    - » Must sign non-disclosure to get access to source code
    - » "Cathedral" model of development: only Microsoft's developers produce code for Windows
  - Linux: open development model
    - » All distributions make source code available to analyze
    - » "Bazaar" model of development: many on the net contribute to making Linux distribution

Windows vs Linux

- Perceptions:
  - Windows has more bugs/is more vulnerable to viruses?
    - » True? Hard to say for sure
    - » More Windows systems ⇒ more interesting for hackers
  - Linux simpler to manage?
    - » True? Well, Windows has hidden info (e.g. registry)
    - » Linux has all configuration available in clear text
  - Microsoft is untrustworthy? Many distrust "the man"
    - » Quick to adopt things like Digital Rights Management (DRM)
    - » Quick to embrace new models of income such as software rental which counter traditional understanding of software
  - Windows is slow?
    - » This definitely seemed to be true with earlier versions
    - » Less true now, but complexity may still get in way
- Why choose one over other?
  - Which has greater diversity of graphical programs?
    - » Probably Windows
  - Which cheaper? Well, versions of Linux are "free
  - Which better for developing code and managing servers?
    - » Probably Linux, although this is changing
    - » OS API (e.g. system calls) definitely seem simpler

Trusted Computing

- Problem: Can't trust that software is correct
  - Viruses/Worms install themselves into kernel or system without users knowledge
  - Rootkit: software tools to conceal running processes, files or system data, which helps an intruder maintain access to a system without the user's knowledge
  - How do you know that software won't leak private information or further compromise user's access?
- A solution: What if there were a secure way to validate all software running on system?
  - Idea: Compute a cryptographic hash of BIOS, Kernel, crucial programs, etc.
  - Then, if hashes don't match, know have problem
- Further extension:
  - Secure attestation: ability to *prove* to a remote party that local machine is running correct software
  - Reason: allow remote user to avoid interacting with compromised system
- Challenge: How to do this in an unhackable way
  - Must have hardware components somewhere

TCPA: Trusted Computing Platform Alliance

- Idea: Add a Trusted Platform Module (TPM)
- Founded in 1999: Compaq, HP, IBM, Intel, Microsoft
- Currently more than 200 members
- Changes to platform
  - Extra: Trusted Platform Module (TPM)
  - Software changes: BIOS + OS
- Main properties
  - Secure bootstrap
  - Platform attestation
  - Protected storage
- Microsoft version:
  - Palladium
  - Note quite same: More extensive hardware/software system

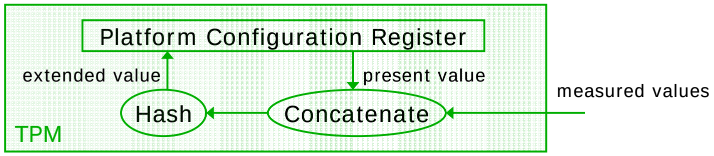
ATMEL TPM Chip
(Used in IBM equipment)

Trusted Platform Module

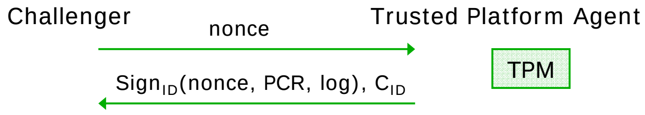
Functional Units	Non-volatile Memory	Volatile Memory
Random Num Generator	Endorsement Key (2048 Bits)	RSA Key Slot-0 … RSA Key Slot-9
SHA-1 Hash	Storage Root Key (2048 Bits)	PCR-0 … PCR-15
HMAC	Owner Auth Secret(160 Bits)	Key Handles
RSA Encrypt/ Decrypt		Auth Session Handles
RSA Key Generation		

- Cryptographic operations
  - Hashing: SHA-1, HMAC
  - Random number generator
  - Asymmetric key generation: RSA (512, 1024, 2048)
  - Asymmetric encryption/ decryption: RSA
  - *Symmetric encryption/ decryption: DES, 3DES (AES)*
- Tamper resistant (hash and key) storage

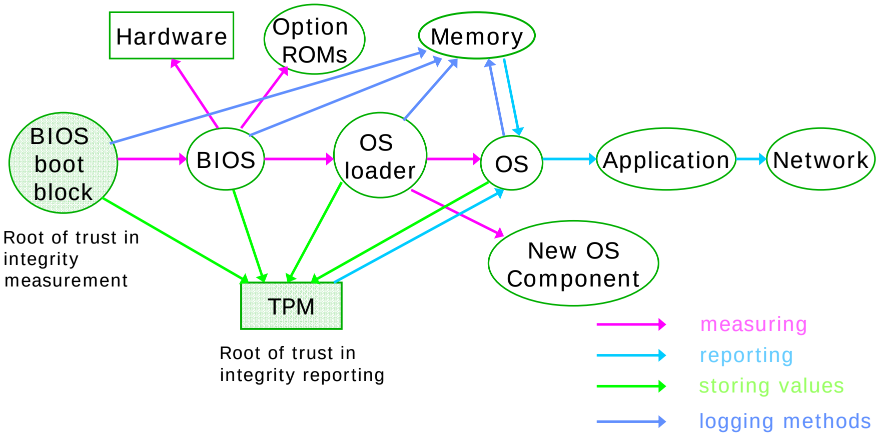
TCPA: PCR Reporting Value



- Platform Configuration Registers (PCR0-16)
  - Reset at boot time to well defined value
  - Only thing that software can do is give new measured value to TPM
    - » TPM takes new value, concatenates with old value, then hashes result together for new PCR
- Measuring involves hashing components of software
- Integrity reporting: report the value of the PCR
  - Challenge-response protocol:



TCPA: Secure bootstrap



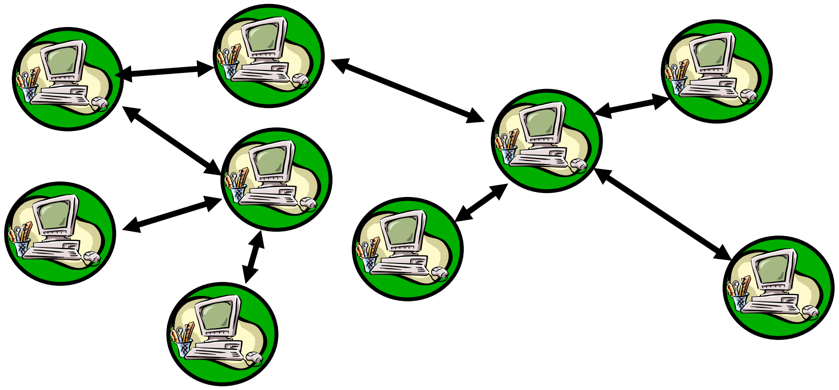
Implications of TPM Philosophy?

- Could have great benefits
  - Prevent use of malicious software
  - Parts of OceanStore would benefit (mention later)
- What does "trusted computing" really mean?
  - You are forced to trust hardware to be correct!
  - Could also mean that user is not trusted to install their own software
- Many in the security community have talked about potential abuses
  - These are only theoretical, but very possible
  - Software fixing
    - » What if companies prevent user from accessing their websites with non-Microsoft browser?
    - » Possible to encrypt data and only decrypt if software still matches ⇒ Could prevent display of .doc files except on Microsoft versions of software
  - Digital Rights Management (DRM):
    - » Prevent playing of music/video except on accepted players
    - » Selling of CDs that only play 3 times?

Administrivia

- Final Exam
  - 12:30 – 3:30, December 17th
  - 220 Hearst Gym
  - Bring 2 sheets of notes, double-sided
- Project 4
  - Due date moved to Friday, 12/9
- Midterm II
  - Still Grading!

Peer-to-Peer: Fully equivalent components



- Peer-to-Peer has many interacting components
  - View system as a set of equivalent nodes
    - » "All nodes are created equal"
  - Any structure on system must be self-organizing
    - » Not based on physical characteristics, location, or ownership

Is Peer-to-peer new?

- Certainly doesn't seem like it
  - What about Usenet? News groups first truly decentralized system
  - DNS? Handles huge number of clients
  - Basic IP? Vastly decentralized, many equivalent routers
- One view: P2P is a reverting to the old internet
  - Remember? (Perhaps you don't)
  - Once upon a time, all members on the internet were trusted.
    - » Every machine had an IP address.
    - » Every machine was a client and server.
    - » Many machines were routers and/or were equivalent
- But: peer-to-peer seems to mean something else
  - More about the *scale* (total number) of directly interacting components
  - Also, has a "bad reputation" (stealing music)

Research Community View of Peer-to-Peer

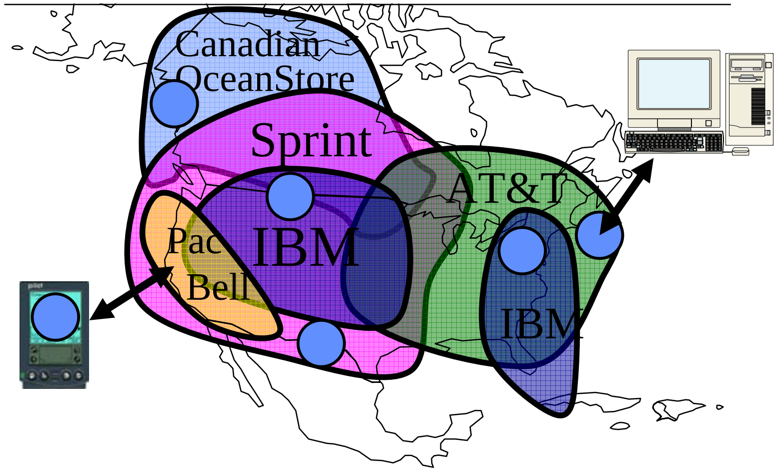
- Old View:
  - A bunch of flakey high-school students stealing music
- New View:
  - A philosophy of systems design at extreme scale
  - Probabilistic design when it is appropriate
  - New techniques aimed at unreliable components
  - A rethinking (and recasting) of distributed algorithms
  - Use of Physical, Biological, and Game-Theoretic techniques to achieve guarantees

Why the hype???

- File Sharing: Napster (+Gnutella, KaZaa, etc)
  - Is this peer-to-peer? Hard to say.
  - Suddenly people could contribute to active global network
    - » High coolness factor
  - Served a high-demand niche: online jukebox
- Anonymity/Privacy/Anarchy: FreeNet, Publis, etc
  - Libertarian dream of freedom from the man
    - » (ISPs? Other 3-letter agencies)
  - Extremely valid concern of Censorship/Privacy
  - In search of copyright violators, RIAA challenging rights to privacy
- Computing: The Grid
  - Scavenge numerous free cycles of the world to do work
  - Seti@Home most visible version of this
- Management: Businesses
  - Businesses have discovered extreme distributed computing
  - Does P2P mean "self-configuring" from equivalent resources?
  - Bound up in "Autonomic Computing Initiative"?

OceanStore

Utility-based Infrastructure



- Data service provided by storage federation
- Cross-administrative domain
- Contractual Quality of Service ("someone to sue")

OceanStore: Everyone's Data, One Big Utility

"The data is just out there"

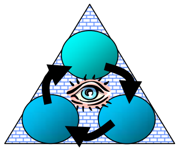
- How many files in the OceanStore?
  - Assume 10^{10} people in world
  - Say 10,000 files/person (very conservative?)
  - So 10^{14} files in OceanStore!
  - If 1 gig files (ok, a stretch), get 1 mole of bytes! (or a Yotta-Byte if you are a computer person)

Truly impressive number of elements…
… but small relative to physical constants

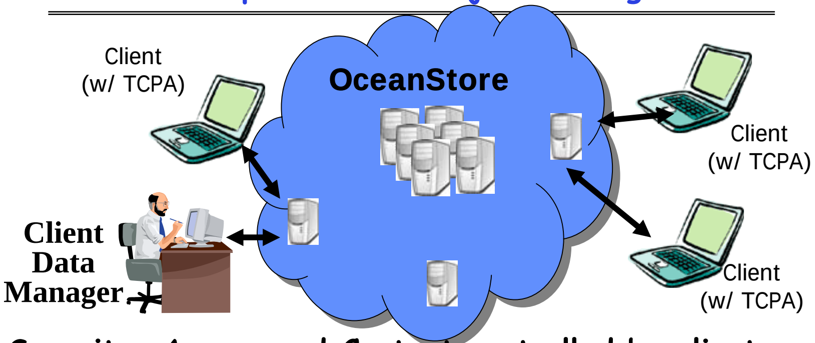
Aside: SIMS school: 1.5 Exabytes/year (1.5×10^{18})

Key Observation: Want Automatic Maintenance

- Can't possibly manage billions of servers by hand!
- System should automatically:
  - Adapt to failure
  - Exclude malicious elements
  - Repair itself
  - Incorporate new elements
- System should be secure and private
  - Encryption, authentication
- System should preserve data over the long term (*accessible* for 1000 years):
  - Geographic distribution of information
  - New servers added from time to time
  - Old servers removed from time to time
  - Everything just works



Example: Secure Object Storage



- Security: Access and Content controlled by client
  - Privacy through data encryption
  - Optional use of cryptographic hardware for revocation
  - Authenticity through hashing and active integrity checking
- Flexible self-management and optimization:
  - Performance and durability
  - Efficient sharing

OceanStore Assumptions

Peer-to-peer

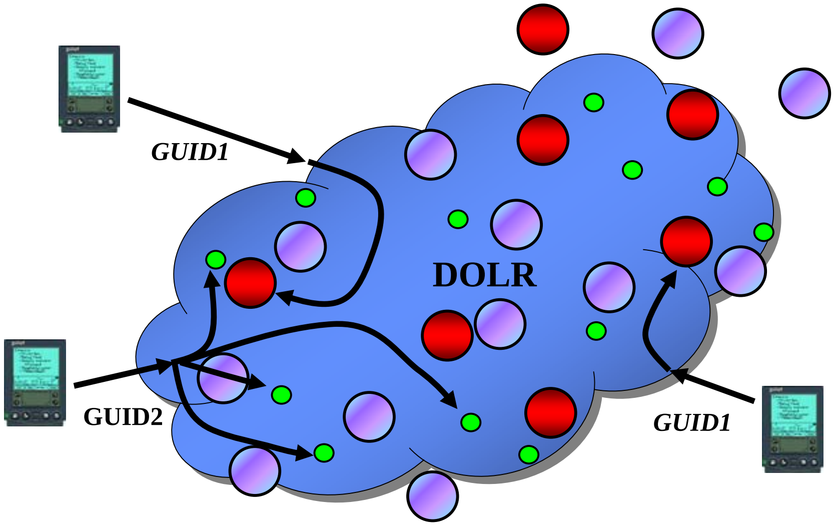
- Untrusted Infrastructure:
  - The OceanStore is comprised of untrusted components
  - Individual hardware has finite lifetimes
  - All data encrypted within the infrastructure
- Mostly Well-Connected:
  - Data producers and consumers are connected to a high-bandwidth network most of the time
  - Exploit multicast for quicker consistency when possible
- Promiscuous Caching:
  - Data may be cached anywhere, anytime

Quality-of-Service

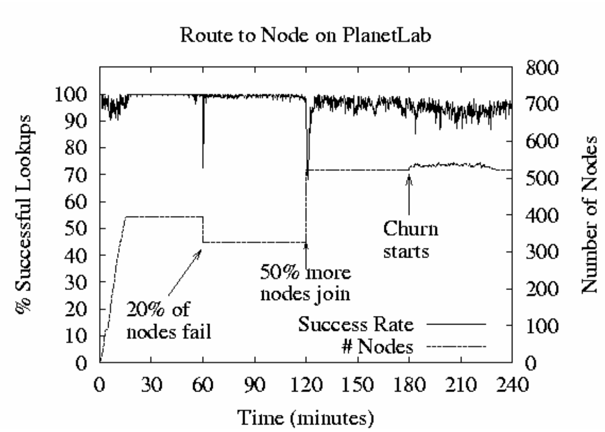
- Responsible Party:
  - Some organization (*i.e. service provider)* guarantees that your data is consistent and durable
  - Not trusted with *content* of data, merely its *integrity*

Peer-to-Peer for Data Location

Peer-to-Peer in OceanStore: DOLR
(Decentralized Object Location and Routing)



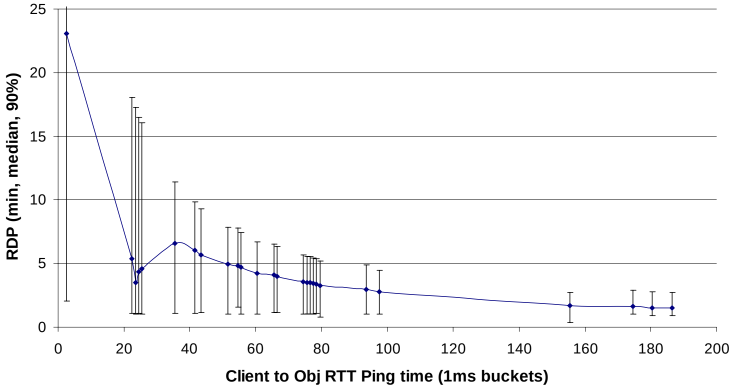
Stability under extreme circumstances



(May 2003: 1.5 TB over 4 hours)

DOLR Model generalizes to many simultaneous apps

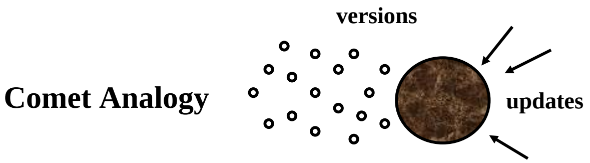
Object Location with Tapestry DOLR



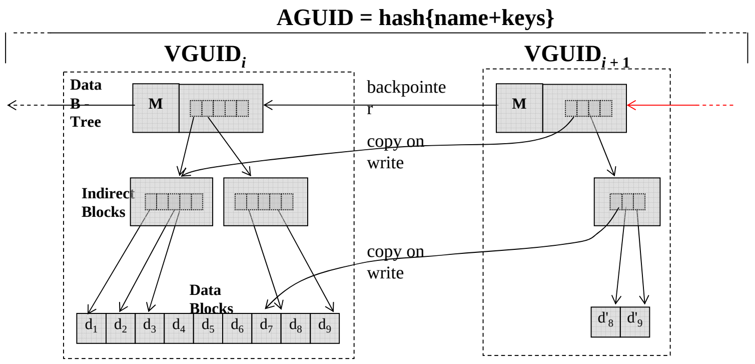
Peek at OceanStore Mechanisms

OceanStore Data Model

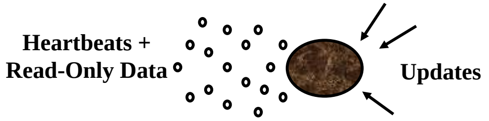
- Versioned Objects
  - Every update generates a new version
  - Can always go back in time (Time Travel)
- Each Version is Read-Only
  - Can have permanent name
  - Much easier to repair
- An Object is a signed mapping between permanent name and latest version
  - Write access control/integrity involves managing these mappings



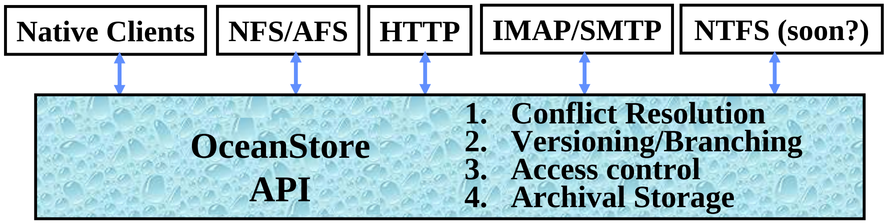
Self-Verifying Objects



♥Heartbeat: $\{$AGUID,VGUID, Timestamp$\}_{\text{signed}}$



OceanStore API: Universal Conflict Resolution



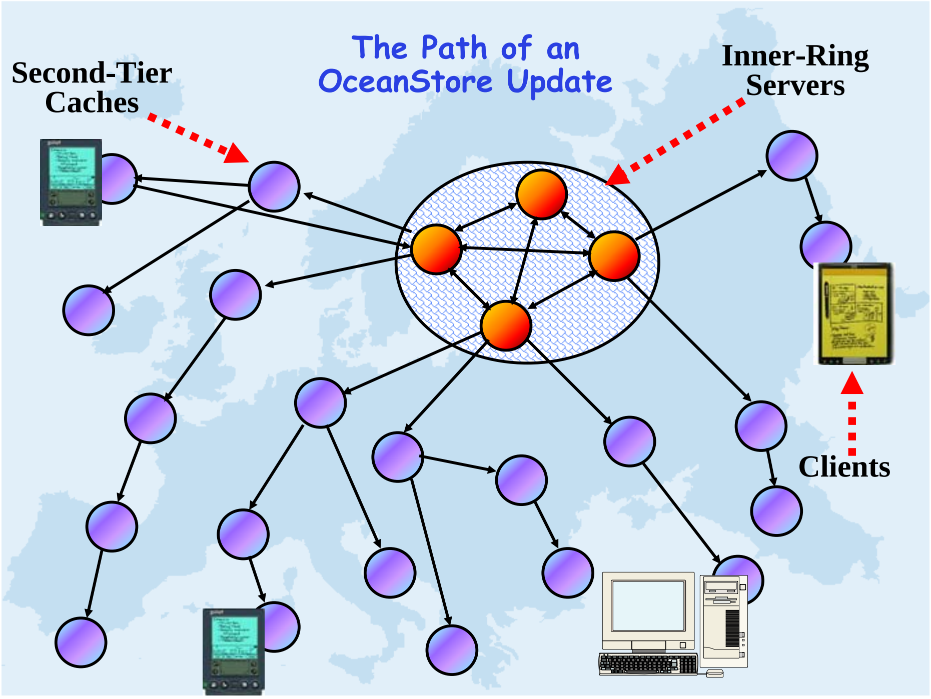
1. Conflict Resolution
2. Versioning/Branching
3. Access control
4. Archival Storage

- Consistency is form of optimistic concurrency
  - Updates contain predicate-action pairs
  - Each predicate tried in turn:
    - » If none match, the update is aborted
    - » Otherwise, action of first true predicate is applied
- Role of Responsible Party (RP):
  - Updates submitted to RP which chooses total order
- This is powerful enough to synthesize:
  - ACID database semantics
  - release consistency (build and use MCS-style locks)
  - Extremely loose (weak) consistency

Two Types of OceanStore Data

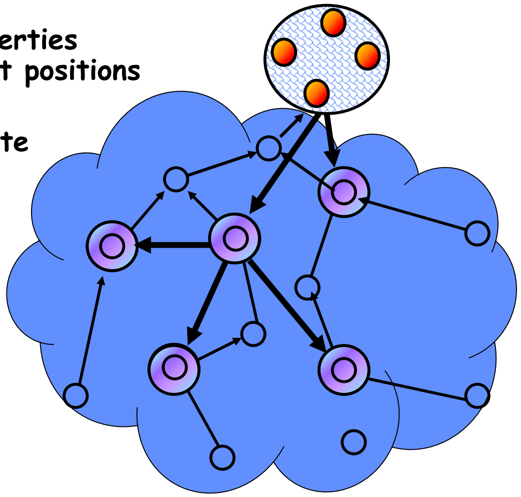
- *Active Data:* “Floating Replicas”
  - Per object virtual server
  - Interaction with other replicas for consistency
  - May appear and disappear like bubbles
- *Archival Data:* OceanStore’s Stable Store
  - m-of-n coding: Like hologram
    - » Data coded into *n* fragments, any *m* of which are sufficient to reconstruct (e.g m=16, n=64)
    - » Coding overhead is proportional to n÷m (e.g 4)
    - » Other parameter, *rate*, is 1/overhead
  - Fragments are cryptographically self-verifying
- Most data in the OceanStore is archival!

The Path of an OceanStore Update

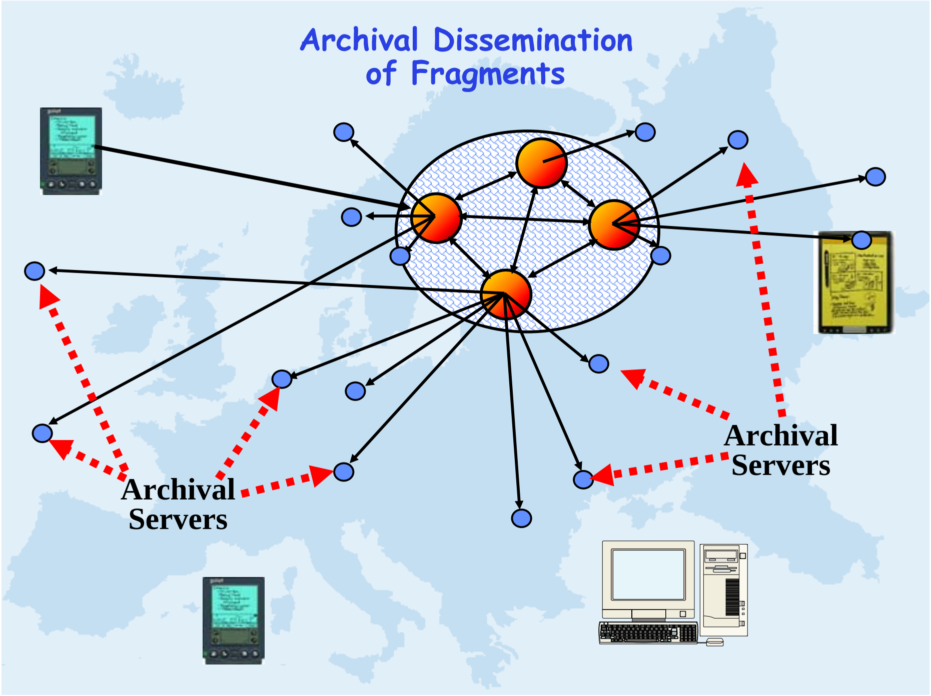


Self-Organizing Soft-State Replication

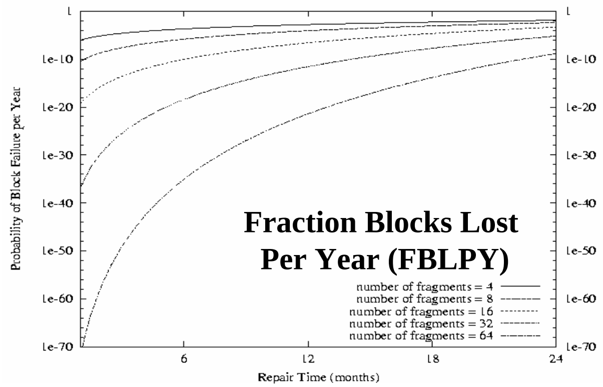
- Simple algorithms for placing replicas on nodes in the interior
  - Intuition: locality properties of Tapestry help select positions for replicas
  - Tapestry helps associate parents and children to build multicast tree
- Preliminary results encouraging
- Current Investigations:
  - Game Theory
  - Thermodynamics



Archival Dissemination of Fragments



Aside: Why erasure coding? High Durability/overhead ratio!



- Exploit law of large numbers for durability!
- 6 month repair, FBLPY:
  - Replication: 0.03
  - Fragmentation: 10-35

Extreme Durability?

- Exploiting Infrastructure for Repair
  - DOLR permits efficient heartbeat mechanism to notice:
    - » Servers going away for a while
    - » Or, going away forever!
  - Continuous sweep through data also possible
  - Erasure Code provides Flexibility in Timing
- Data transferred from physical medium to physical medium
  - No "tapes decaying in basement"
  - Information becomes fully Virtualized
- Thermodynamic Analogy: Use of Energy (supplied by servers) to Suppress Entropy

Differing Degrees of Responsibility

- Inner-ring provides quality of service
  - Handles of live data and write access control
  - Focus utility resources on this vital service
  - Compromised servers must be detected quickly
- Caching service can be provided by anyone
  - Data encrypted and self-verifying
  - Pay for service "Caching Kiosks"?
- Archival Storage and Repair
  - Read-only data: easier to authenticate and repair
  - Tradeoff redundancy for responsiveness
- Could be provided by different companies!

Closing View on Peer-to-Peer

Peer-to-peer Goal: Stable, large-scale systems

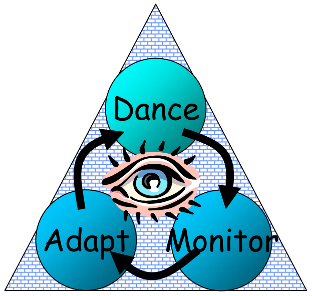
- State of the art:
  - Chips: 10^8 transistors, 8 layers of metal
  - Internet: 10^9 hosts, terabytes of bisection bandwidth
  - Societies: 10^8 to 10^9 people, 6-degrees of separation
- Complexity is a liability!
  - More components ⇒ Higher failure rate
  - Chip verification > 50% of design team
  - Large societies unstable (especially when centralized)
  - Small, simple, perfect components combine to generate complex emergent behavior!
- Can complexity be a useful thing?
  - Redundancy and interaction can yield stable behavior
  - Better figure out new ways to design things…

Exploiting Numbers: Thermodynamic Analogy

- Large Systems have a variety of *latent order*
  - Connections between elements
  - Mathematical structure (erasure coding, etc)
  - Distributions peaked about some desired behavior
- Permits "Stability through Statistics"
  - Exploit the behavior of aggregates (redundancy)
- Subject to Entropy
  - Servers fail, attacks happen, system changes
- Requires continuous repair
  - Apply energy (i.e. through servers) to reduce entropy

Exploiting Numbers: The Biological Inspiration

- Biological Systems are built from (extremely) faulty components, yet:
  - They operate with a variety of component failures ⇒ Redundancy of function and representation
  - They have stable behavior ⇒ Negative feedback
  - They are self-tuning ⇒ Optimization of common case
- Introspective (Autonomic) Computing:
  - Components for performing
  - Components for monitoring and model building
  - Components for continuous adaptation



What does this really mean?

- Redundancy, Redundancy, Redundancy:
  - Many components that are roughly equivalent
  - System stabilized by consulting multiple elements
  - Voting/signature checking to exclude bad elements
  - Averaged behavior/Median behavior/First Arriving
- Passive Stabilization
  - Elements interact to self-correct each other
  - Constant resource shuffling
- Active Stabilization
  - Reevaluate and Restore good properties on wider scale
  - System-wide property validation
  - Negative feedback/chaotic attractor
- Observation and Monitoring
  - Aggregate external information to find hidden order
  - Use to tune functional behavior and recognize dysfunctional behavior.

Problems?

- Most people don't know how to think about this
  - Requires new way of thinking
  - Some domains closer to thermodynamic realm than others:
    peer-to-peer networks fit well
- Stability?
  - Positive feedback/oscillation easy to get accidentally
- Cost?
  - Power, bandwidth, storage, ….
- Correctness?
  - System behavior achieved as aggregate behavior
  - Need to design around fixed point or chaotic attractor behavior (How does one think about this)?
  - Strong properties harder to guarantee
- Bad case could be quite bad!
  - Poorly designed ⇒Fragile to directed attacks
  - Redundancy below threshold ⇒ failure rate increases drastically

Conclusions

- Windows vs Linux:
  - Graphics vs Server?
  - Cathedral vs Bazaar
  - Controlled vs Free
- Trusted Computing
  - Hardware to allow software attestation, secure storage
- Peer to Peer
  - A philosophy of systems design at extreme scale
  - Probabilistic design when it is appropriate
  - New techniques aimed at unreliable components
  - A rethinking (and recasting) of distributed algorithms
  - Use of Physical, Biological, and Game-Theoretic techniques to achieve guarantees
- Let's give a hand to the TAs!
  - Clap, clap, clap, clap
- Good Bye!
  - You guys have been great!