Survivable Storage

- This part of the discussion of survivable storage is based on the CMU paper below [Wylie-2001].

- "Selecting the Right Data Distribution Scheme for a Survivable Storage System",
  - Jay J. Wylie, Mehmet Bakkaloglu, Vijay Pandurangan,Michael W. Bigrigg, Semih Oguz, Ken Tew, Cory Williams, Gregory R. Ganger, Pradeep K. Khosla
  - May 2001
  - CMU-CS-01-120

Survivable Storage

- Design based on mature technologies from decentralized storage systems
- Key issues is the selection of the data distribution scheme
  - specific algorithms for data encoding and partitioning
  - set of values for its parameters
- Algorithms are based on
  - encryption
  - replication
  - striping
  - erasure-resilient coding
  - secret sharing
  - combinations of the above

Survivable Storage

- Each algorithm has tunable parameters
- Results are schemes using different levels of
  - performance
    - e.g. throughput
  - availability
    - probability that data is accessible
  - security
    - effort required to compromise confidentiality and integrity of stored data

Survivable Storage

- Example
  - replication results in high availability but at high cost with respect to network bandwidth and storage
  - secret sharing provides security at lower storage and bandwidth cost
    - disadvantage includes higher CPU utilization
    - what happens if the number of shares increases?

Survivable Storage

- There is no snake oil!
  - life is a compromise
- Paper enumerates on
  - possible data distribution schemes
    - <algorithm, parameters>
  - modeling the consequences of the schemes
  - identification of best approach for given requirements

Survivable Storage

[Wylie-2001] figure 1

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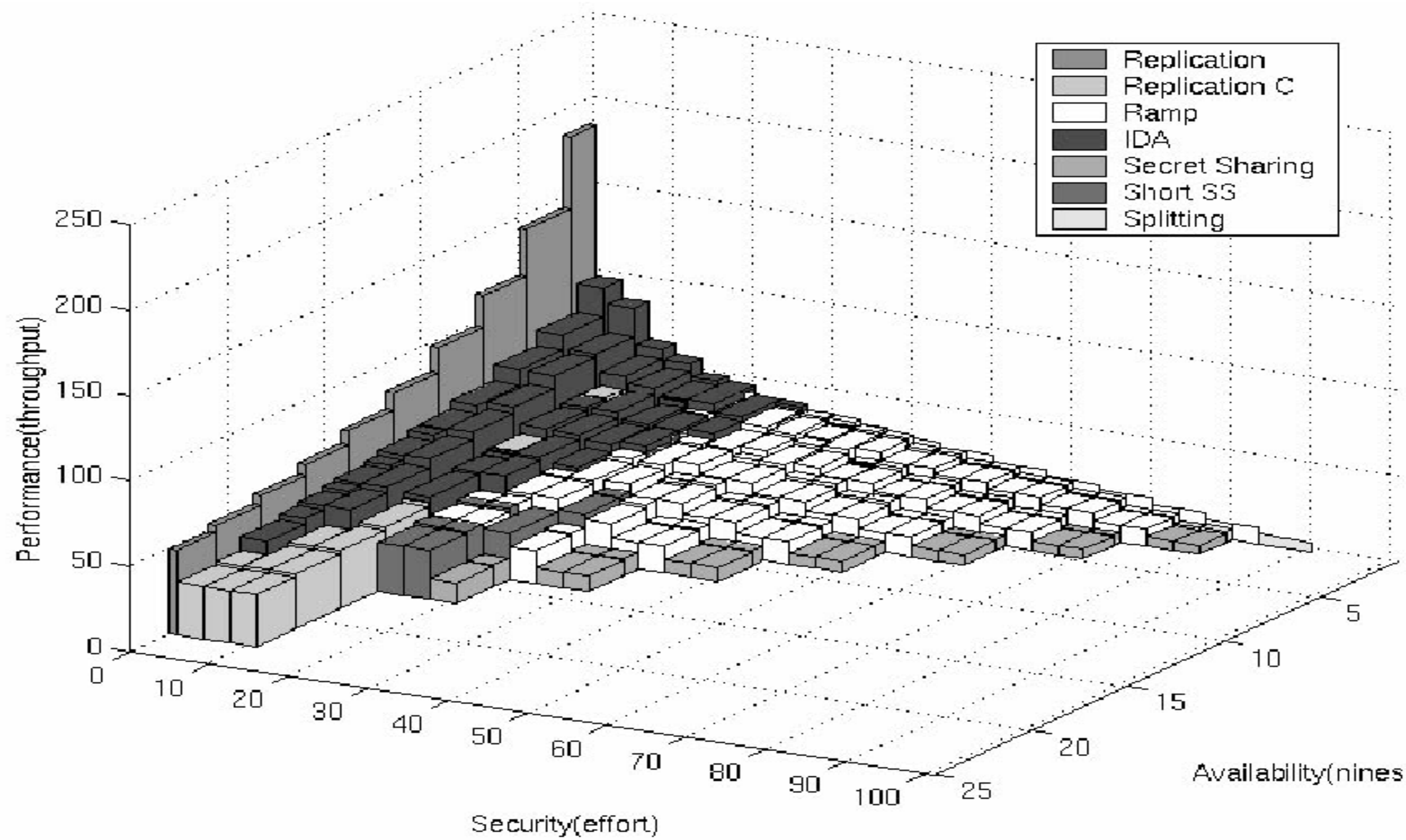


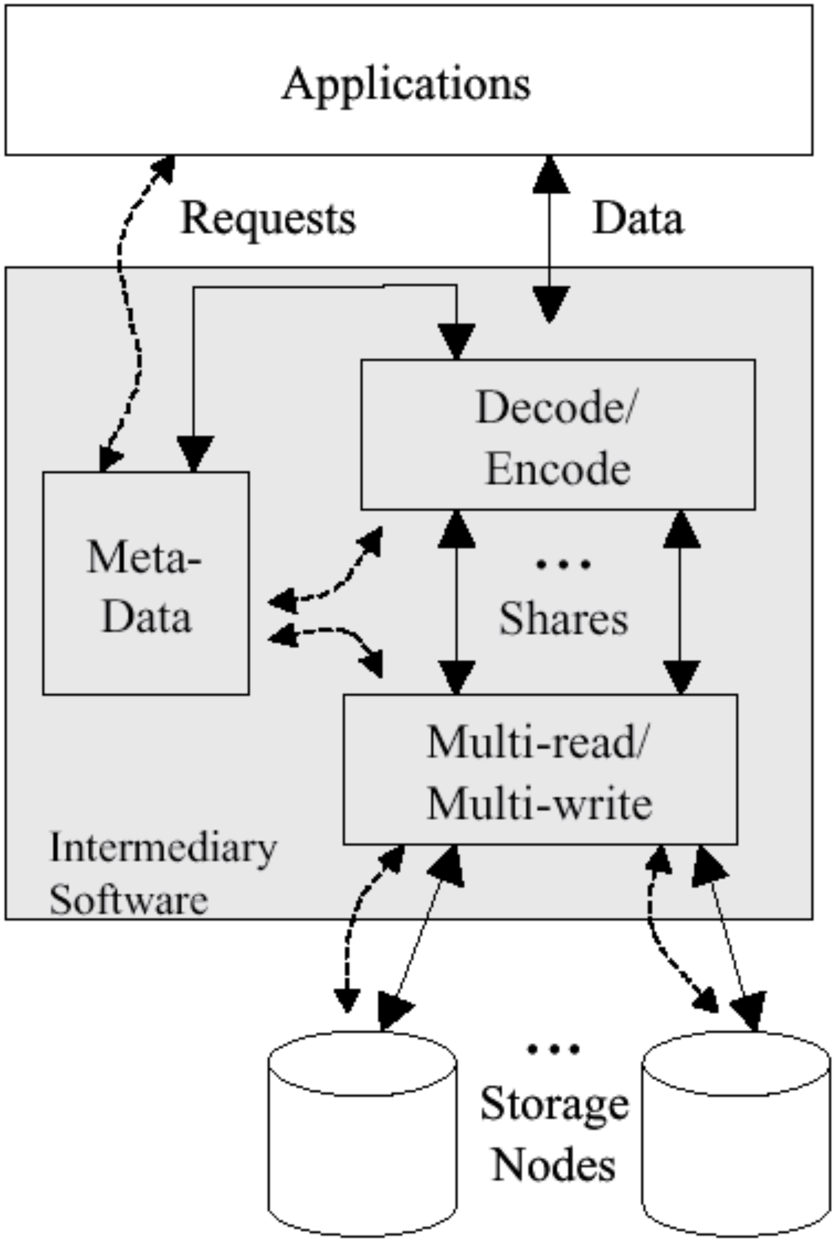
Survivable Storage

- Assumptions
  - no individual service, node, or user can be fully trusted
  - view compromised entities as common rather than the exception
  - encode and distribute data across independent storage nodes
  - if confidentiality is required
    - unencoded data should not be stored on single node

Survivable Storage

[Wylie-2001] figure 2

- Generic decentralized storage architecture
  - solid lines trace data path
  - dashed lines trace metadata path



Survivable Storage

- Threshold algorithms
  - encryption, replication, striping, erasure resilient coding, information dispersal, secret sharing
  - 3 parameters (p,m,n)
    - n: data is encoded into n shares
    - m: any m shares can reconstruct the data
    - p: less than p shares reveal no information about the encoded data

Survivable Storage

- Replication (1,1,n)
  - n replicas are stored
  - any single replica provides the entire data (m=1)
  - each replica reveals information about the data, in this case, about *all* the data (p=1)

Survivable Storage

- Striping (1,n,n)
  - large block of data is partitioned into n equally sized blocks
  - need all n sub-blocks to retrieve the data
  - each sub-block reveals some information
- Splitting (n,n,n)
  - n-1 sub-blocks contain random values, 1 value is EXOR of the n-1 values and the original value
  - all n sub-blocks are needed to extract the data, hence $p=m=n$

Survivable Storage

- Secret sharing (m,m,n)
  - need m components to reassemble the data
  - possible implementation
    - » interpolation points on a polynomial in a finite field
    - » secret value together with m-1 random values determines the encoding polynomial of order m-1

Survivable Storage

- [Ganger-2001]

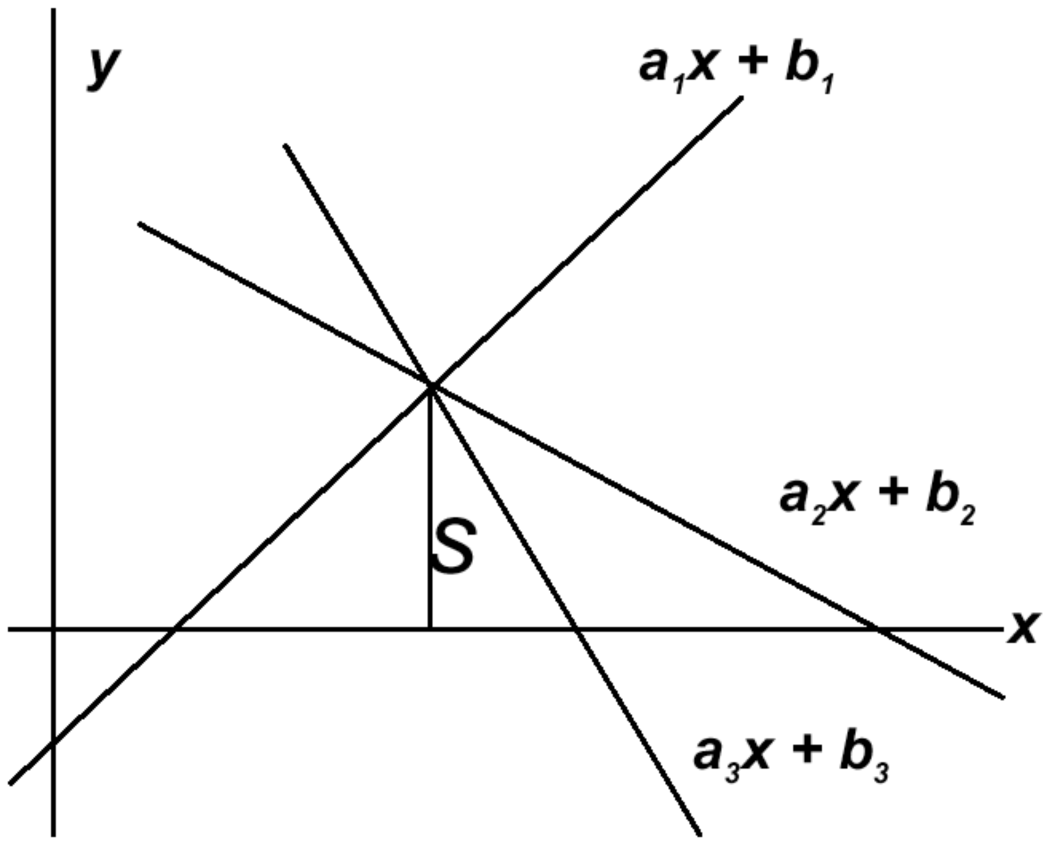


Figure 1. Blakley's secret sharing scheme with *m*=2, *n*=3, and original data *S*.

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Survivable Storage

- Ramp scheme (*p*,*m*,*n*)
  - can be implemented using polynomial-based math
  - *p*-1 random values and *m*-(*p*-1) secret values
  - for *p*=1 this is equivalent to information dispersal
  - for *p*=*m* this is equivalent to secret sharing

Survivable Storage

- In general
  - given *N* storage nodes there are N^3 different options to consider
  - considerations
    - availability
    - confidentiality
    - CPU cost
    - storage requirements
      - implies network bandwidth

Survivable Storage

- Encryption
  - common approach to protection of confidential data
  - Symmetric key encryption
    - single parameter, i.e. key length
  - Hybrid data distribution algorithms
    - combining replication with encryption
    - two security issues:
      - how well is key protected
      - how difficult is crypto-analysis

Survivable Storage

- Encryption cont.
  - Short Secret Sharing
    - encrypt original with random key
    - store key using secret sharing
    - store encrypted data using information dispersal
    - parameters are *m, n*, and *k* (key length)
  - Compression
    - can be applied to data before applying other algorithms
    - reduce size of data

Survivable Storage

- Encryption cont.
  - Cryptographic algorithms
    - e.g. MD5, SHA-2
    - can be applied before encoding and used to verify data integrity
    - store signature with data or separate

Availability

- Evaluating Availability
  - Typical assumptions
    - » independence of failure, i.e. uncorrelated failures
  - example (*p*,*m*,*n*) threshold scheme
    - » this is basically an *m*-of-*n* system in fault-tolerance
      - but, be aware of the implications of the fault model,
        - e.g. benign vs. malicious
    - » let f_{node} be the probability that a node has failed or is unavailable
    - » the "read" availability of the stored information is

$$Availability_{read} = \sum_{i=0}^{n-m} \binom{n}{i} (f_{node})^i (1 - f_{node})^{n-i}$$

Availability

- example (p,m,n) threshold scheme
  - write operations are more complicated
  - system could require *m* to *n* nodes to operate correctly to write
  - if *n* nodes are required => poor availability
  - assume N > *n* storage nodes
  - now write operation is finished if *n* shares have been written
    - this is essentially an n-of-N system
  - if an *m*-of-*N* system is assumed, recovery would be more complicated
    - paper assumes this approach

$$Availability_{write} = \sum_{i=0}^{N-m} \binom{N}{i} (f_{node})^i (1 - f_{node})^{N-i}$$

Availability

- availability discussion
  - requirements for availability are high, 0.9999…x
  - how realistic is the assumption that failures are uncorrelated?
    - e.g. DoS attack, what are the consequences w.r.t. availability?
    - availability measures are meaningless (!)
    - availability measure are useful (!)

Security

- Evaluating Security
  - How does one measure security?
    - no proven metric available to date
  - One approach: reuse mathematics of fault tolerance
    - how many nodes must be compromised to bypass confidentiality or integrity?
    - e.g. use fault-model approach, use PRA
    - potential problems:
      - need probabilities of being compromised
      - difficult or impossible to estimate such probabilities
      - attacks are often very correlated
        - problem with independence of faults assumption
      - how does one include concepts like encryption?
        - e.g. node is taken over, but data is still safe

Security

- Level of Effort
  - paper uses "effort (E) required for an active foe to compromise the security of the system"
  - example (n,n,n)
    - threshold is n
    - assume that no encryption used
    - two ways to break system
      - break authentication
      - break in all n systems
    - effort to break confidentiality

$$E_{Conf} = \min\left[E_{Auth}, (n \times E_{BreakIn})\right]$$

Security

- example (n,n,n)
  - this time assume encryption is used
  - several ways to break the system
    - attempt to break the code after getting the data
    - get data and steal the key
    - trick the authentication system
  - effort to break confidentiality

$$E_{Conf} = \min\left[E_{Auth}, (n \times E_{BreakIn}) + \min\left[E_{Cryptanalysis}, E_{StealKey}\right] + \min\left[E_{IdentifyShares}, E_{StealNames}\right]\right]$$

Security

- paper uses effort units on the security axis
  - normalized to (0 to 100)
- $E_{breakIn}$ is assumed constant for all nodes
  - how realistic is this?
  - given the assumption, what constitutes a homogeneous and heterogeneous systems?
    - this is a bit different to the terms used in computer architecture

Security

- Security definition
  - combined term to address
    - availability
    - confidentiality
    - integrity
  - paper considers confidentiality only
    - availability is on separate axis
    - integrity can be dealt with quite effectively and predictably

Performance

- Evaluating Performance
  - Model considers
    - CPU time for encoding and decoding
    - network bandwidth
    - storage node response time

Performance

- CPU Time
  - encoding and decoding uses CPU extensively
  - different schemes have different cost, differing by orders of magnitude
  - Figure from paper considers 32kB block for (p,m,n) threshold scheme
    - $n < 26$, different m are considered

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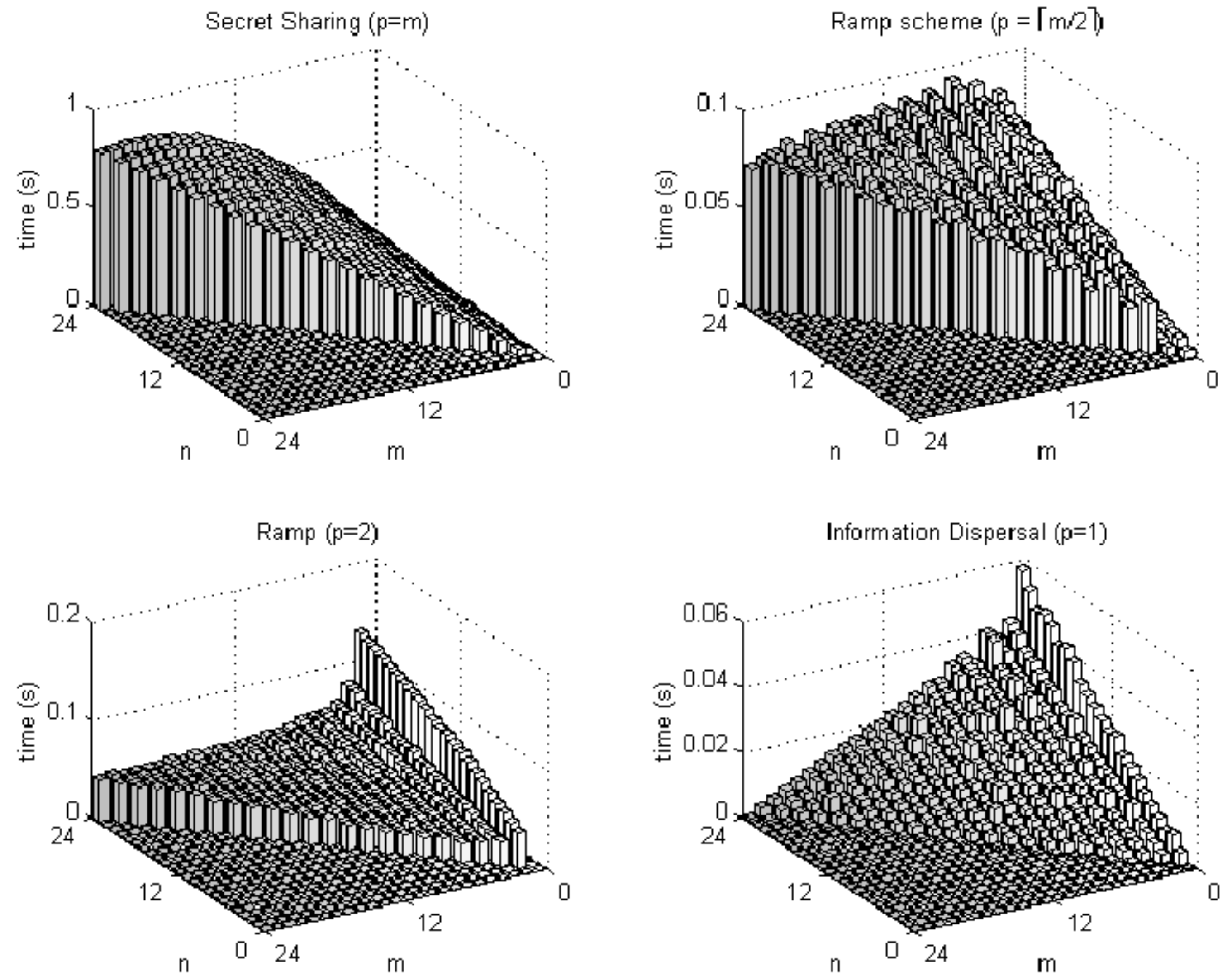

Figure 3: **Measured encode times for 32 KB blocks on a 600 MHz Pentium III.** All m and n combinations up to $n = 25$ are shown for four threshold schemes: secret sharing (p=m), ramp scheme with $p = \lceil m/2 \rceil$, ramp scheme with $p = 2$, and information dispersal ($p = 1$).

Performance

- Network Bandwidth
  - bandwidth depends on
    - read-write ratio,
    - values for p,m, and n

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  - size of each share is equal to original size divided by $m-(p-1)$
    - example (1,1,4) scheme
      - 4-fold data redundancy
    - example (1,2,4) scheme
      - now only 2-fold redundancy, i.e. data redundancy is half
  - assumptions
    - write: all n shares must be updated
    - read: only m shares are requested

Performance

- Network Bandwidth
  - single bottleneck link determines the aggregate bandwidth
  - Where is the bottleneck?
    - LAN or dial-up: client NIC
    - WAN: link at edge router through which client interacts

Performance

- Storage Node Latency
  - two issues to consider
    - getting data at storage node
    - moving data over the network
  - client only sees the combined response time latency
    - modeling should consider both delays separately

Performance

- Overall performance model
  - for write sum:
    - CPU time +
    - storage node latency to write one share to one server +
    - *n* times the network transition time per share
  - for read:
    - same in reverse, however only *m* shares are needed