Physical Modeling of Probe-Based Storage

Tara Madhyastha
Katherine Pu Yang

University of California Santa Cruz

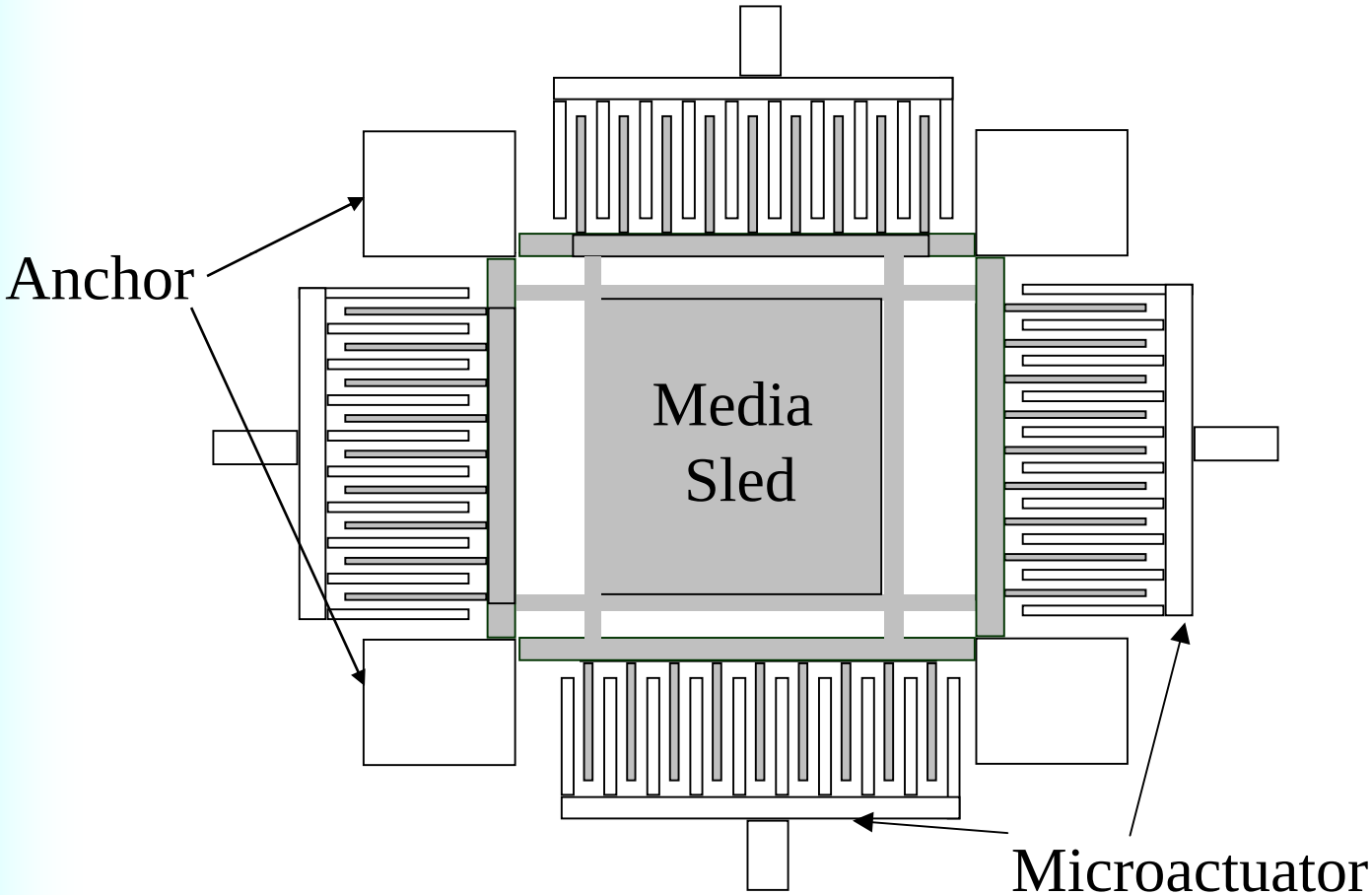
Motivation

- Superparamagnetic limit
- Novel storage technologies can achieve higher densities
- Must understand how to use them in systems

Overview

- Probe-based storage
- Physical models
- Evaluation
- Conclusions

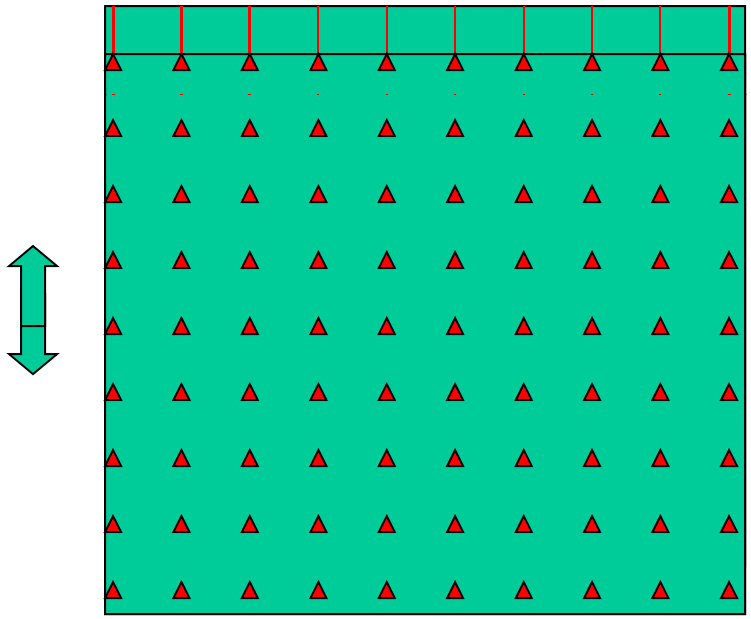
Probe-Based Storage Device



Characteristics

- Low power
- Density 50nm/bit
- 100-200Kbit/sec per tip
- Highly parallel tip arrays
- Rectilinear motion

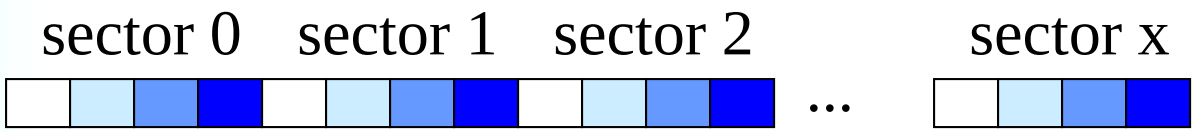
Data Layout

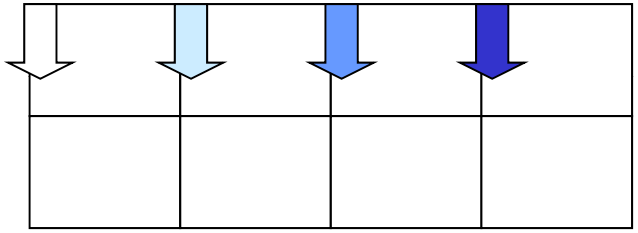


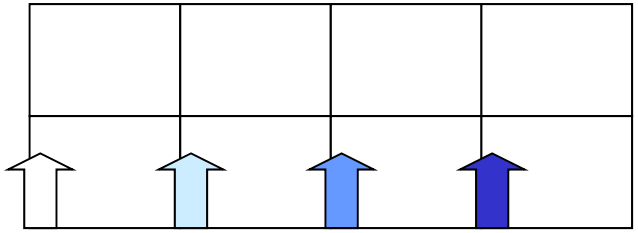
tip row 1 reads

tip row 2 reads

Sector Mapping

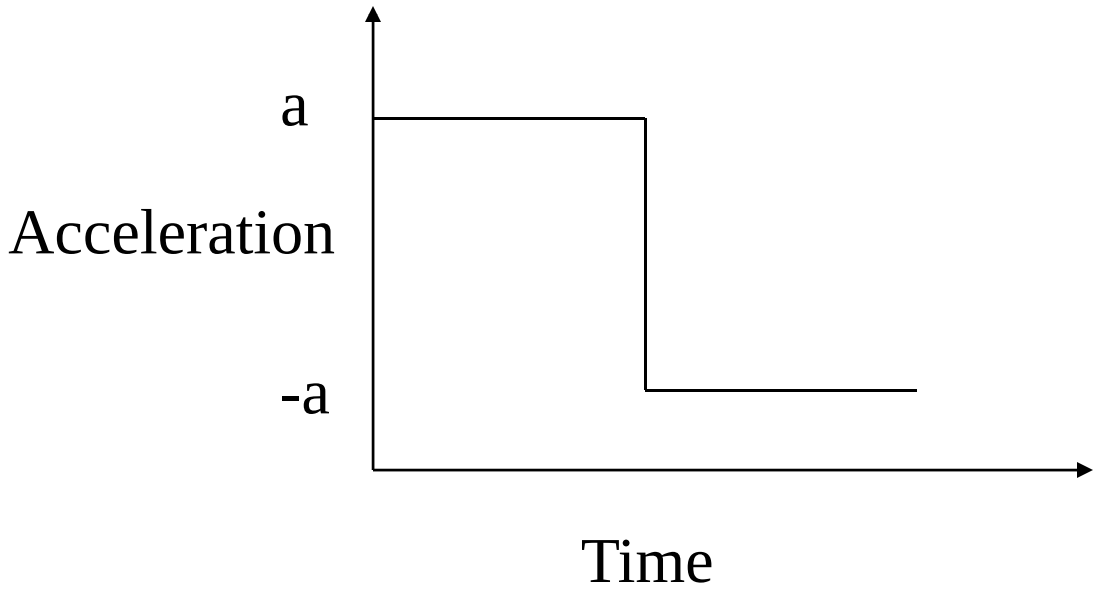




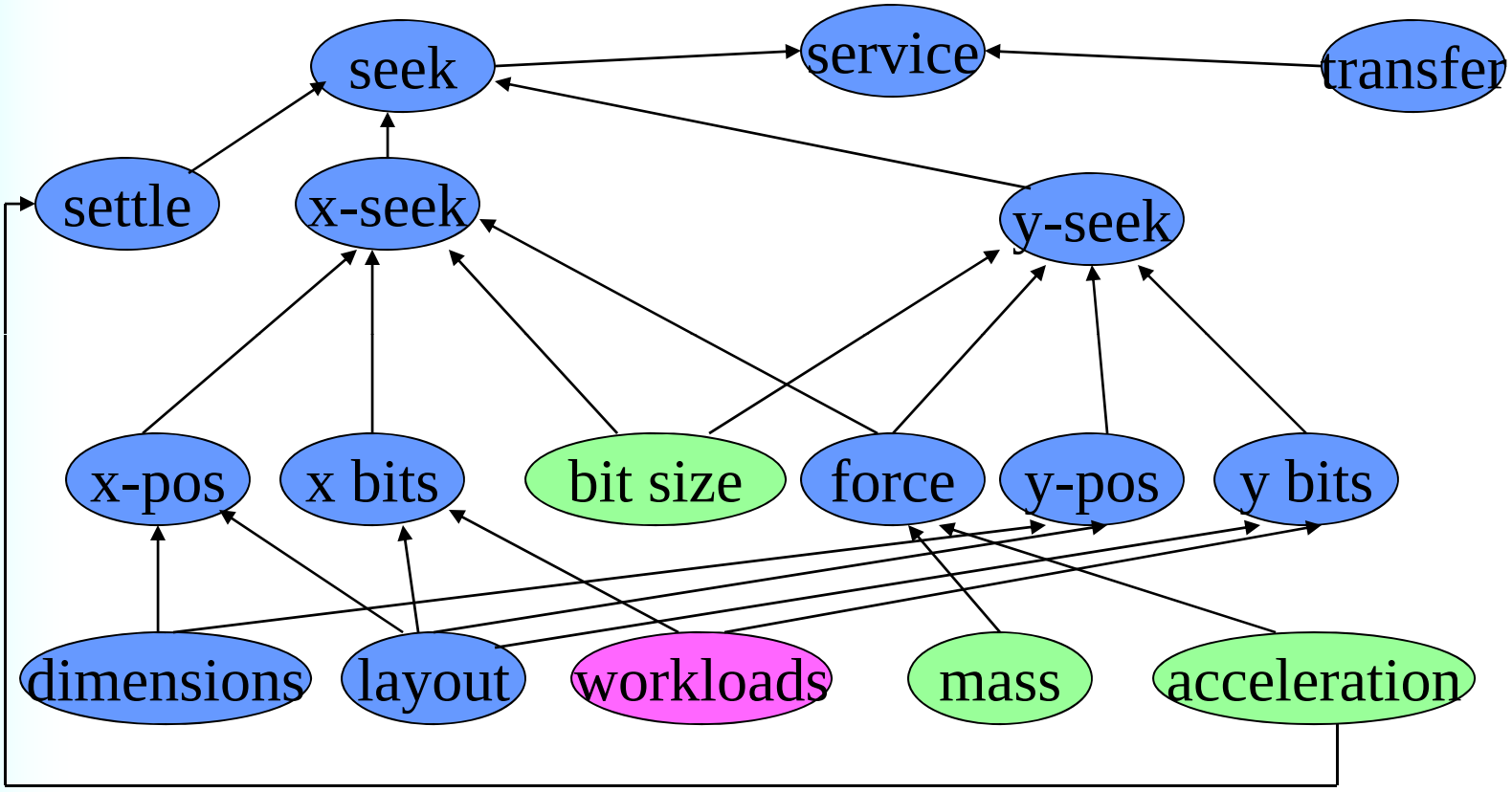


Unconstrained Sled Model

$$t_{seek} = 2\sqrt{\frac{x_f - x_0}{a}} + t_{settle}$$

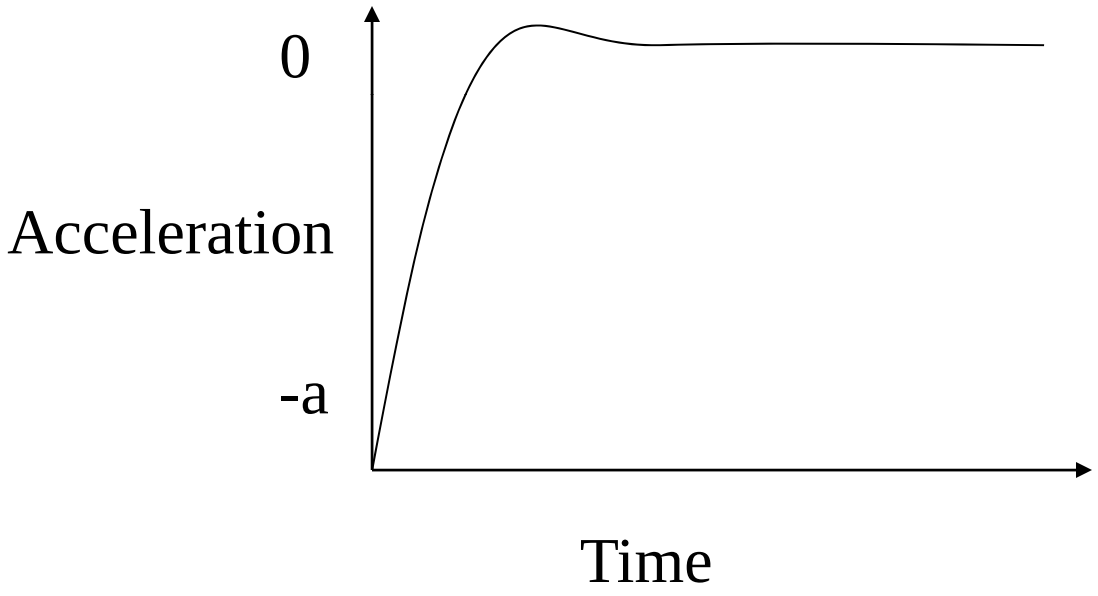


Dependencies Graph



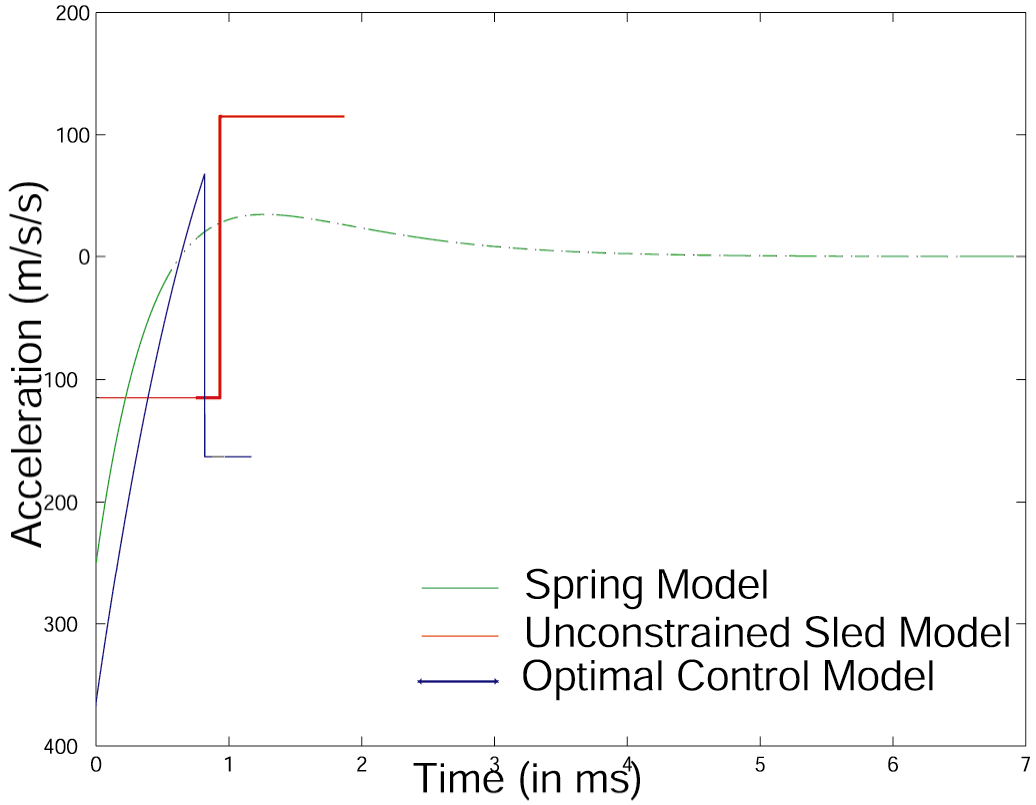
Spring Model

$$mx'' + \lambda x' + kx = \frac{F}{k}$$



Optimal Control Model

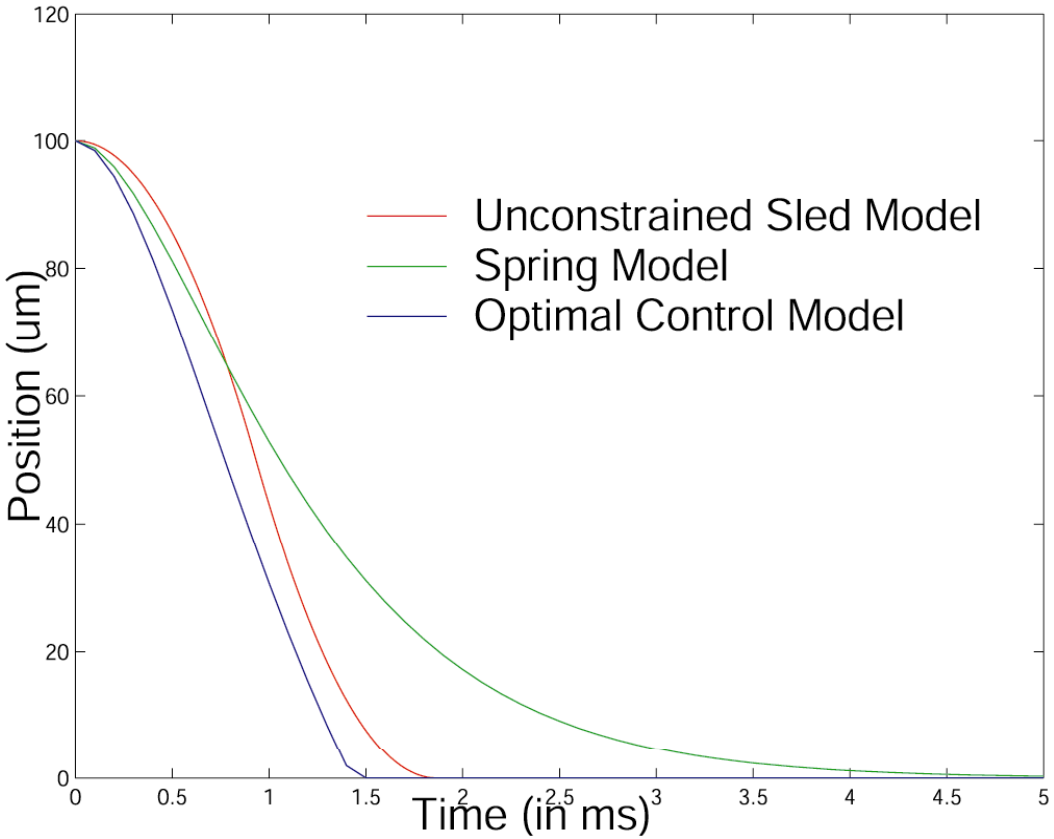
$$mx'' + \lambda x' + kx = F(t)$$



Overview of Physical Models

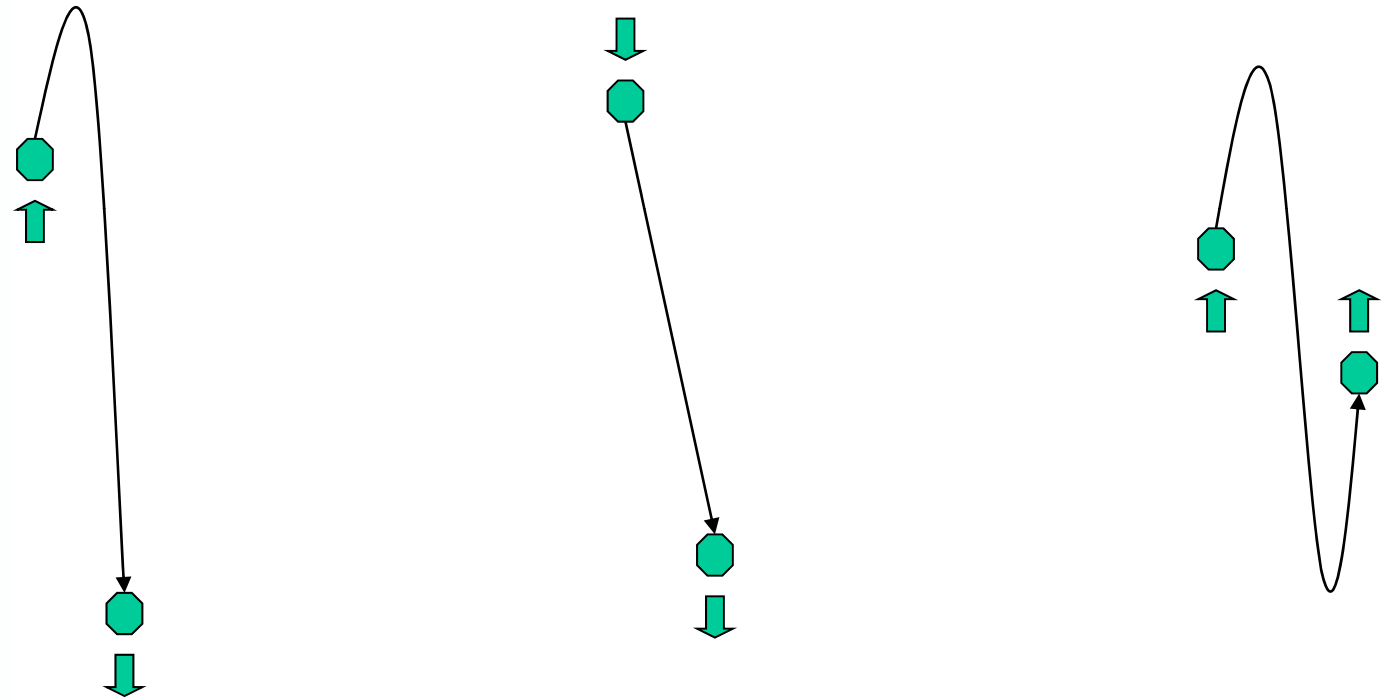
- Unconstrained sled
  - max acceleration/deceleration
- Spring model
  - constant force
- Optimal control
  - optimally varying force

Model Dynamics



- optimal control predicts shortest seeks
- spring model predicts longest seeks

Turnaround Time



- Models do not incorporate turnaround time

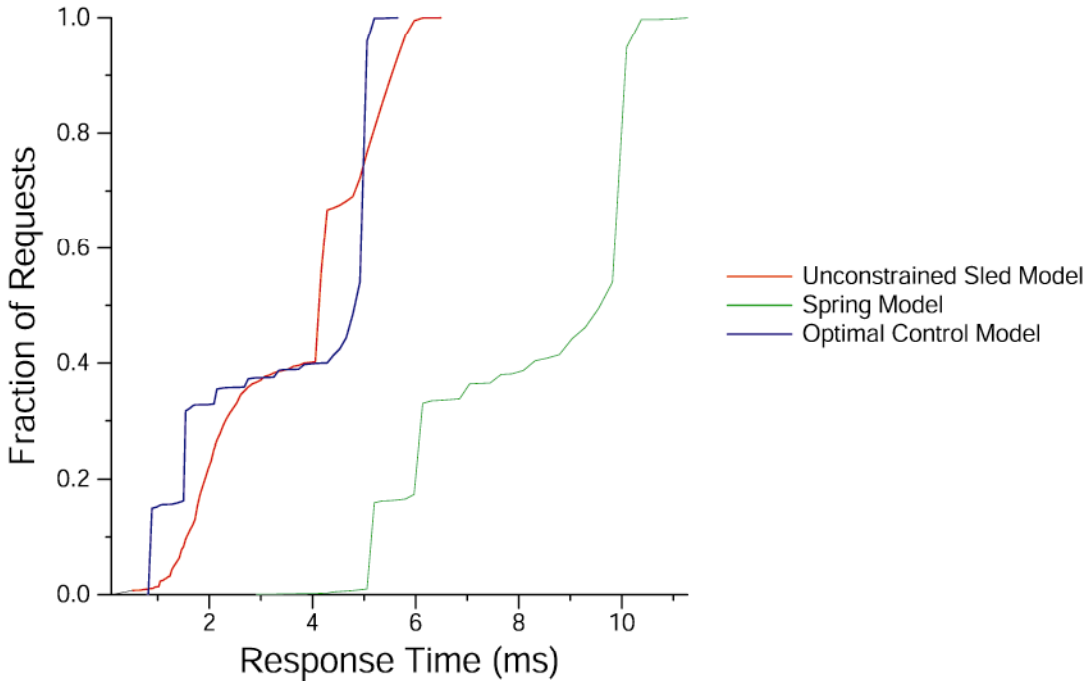
Device Parameters

Parameter	Description
m	mass
F	external force
k	spring coefficient
λ	damping coefficient
ω	resonant frequency
a	acceleration
t_{tol}	tolerance
t_{settle}	settle time

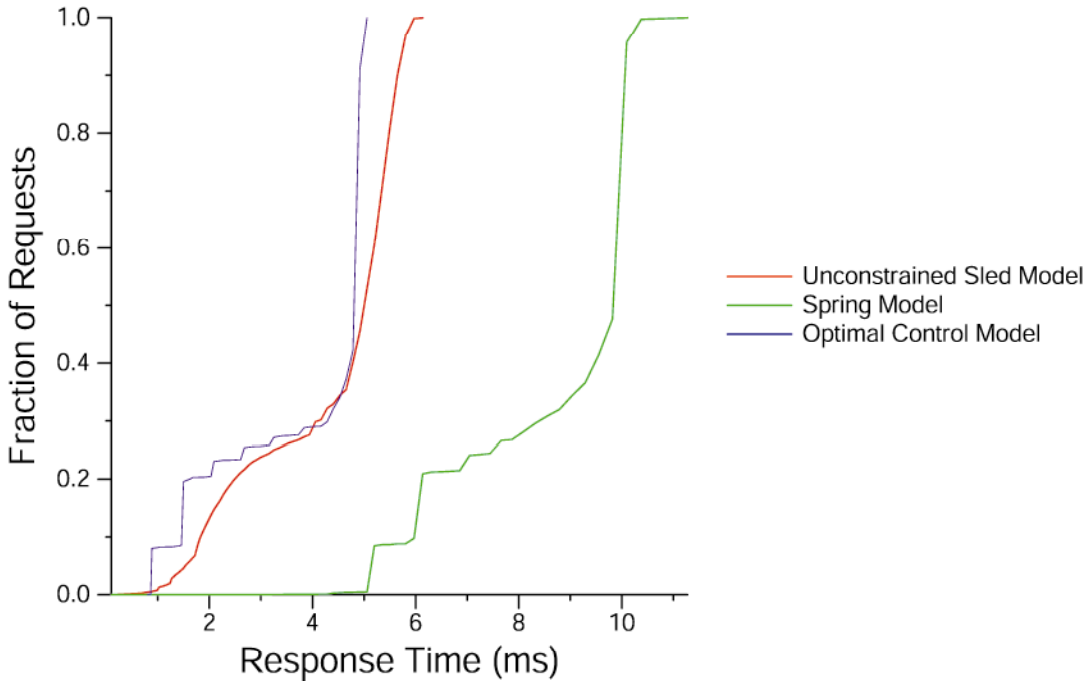
Evaluation

- Pantheon simulator
- Cello (4% sequential)
- Snake (38% sequential)

Snake usr1


1.0
0.8
0.6
0.4
0.2
0.0
Fraction of Requests
2
4
6
8
10
Response Time (ms)
Unconstrained Sled Model
Spring Model
Optimal Control Model

Cello news


1.0
0.8
0.6
0.4
0.2
0.0
Fraction of Requests
2
4
6
8
10
Response Time (ms)
Unconstrained Sled Model
Spring Model
Optimal Control Model

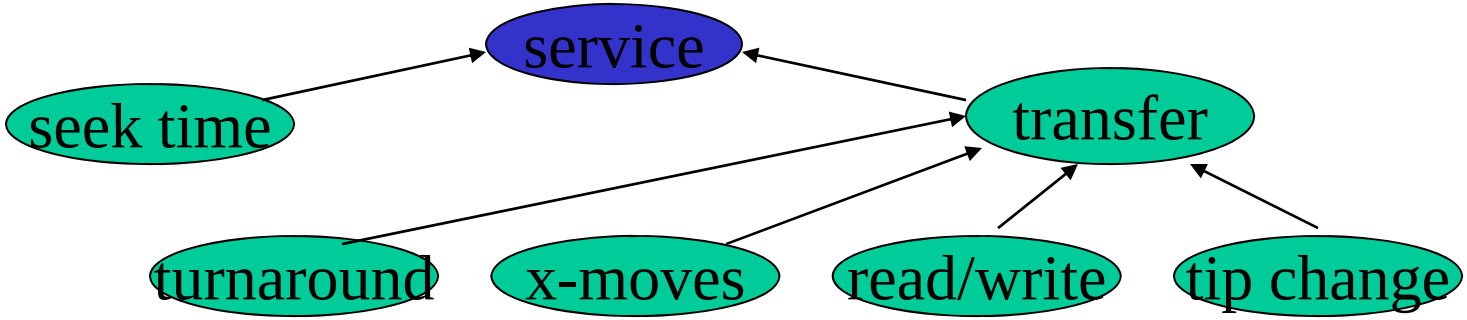
Summary

- Upper bound: spring model
- Lower bound: optimal control model
- Settle time

Questions

- How significant is seek time/transfer time?
- Different models/different conclusions?

Transfer Time



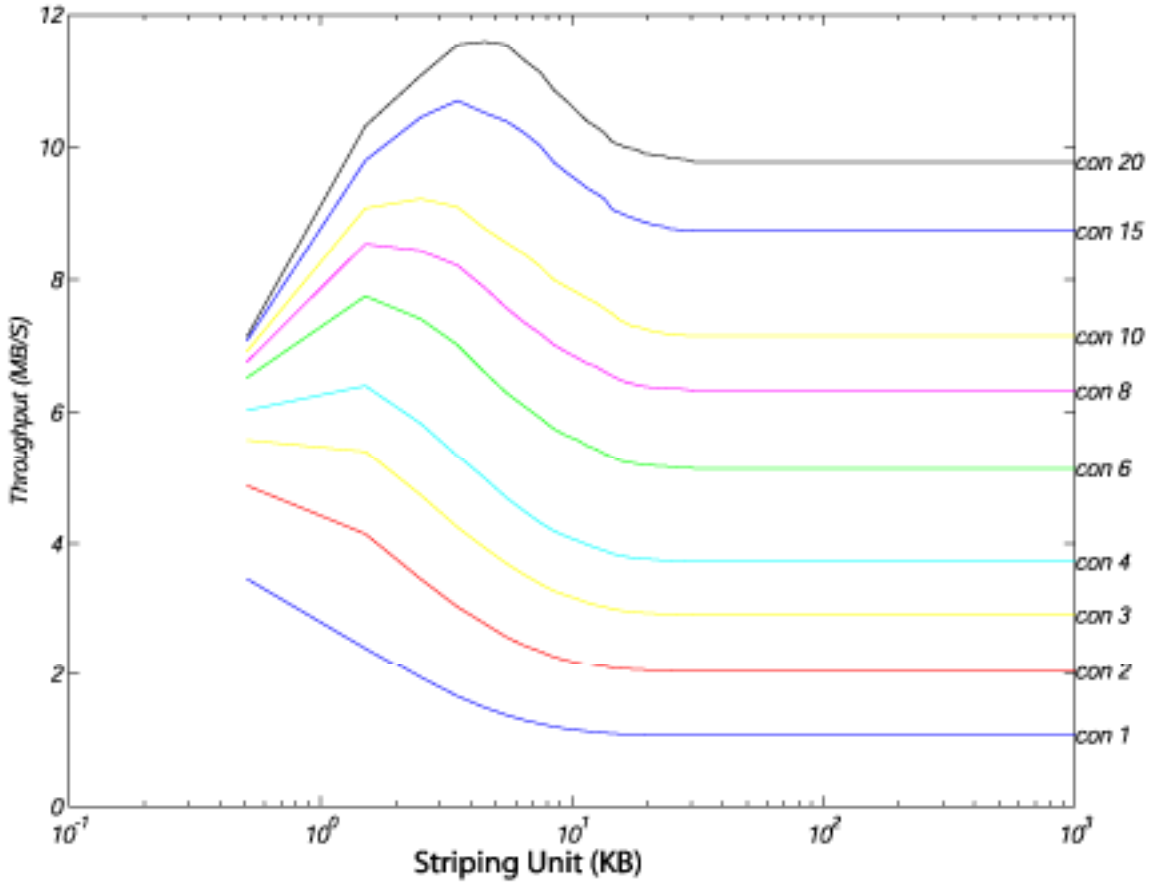
Seek Time

- Transfer time dominates seeks for requests > 4KB
- Potentially even larger than that

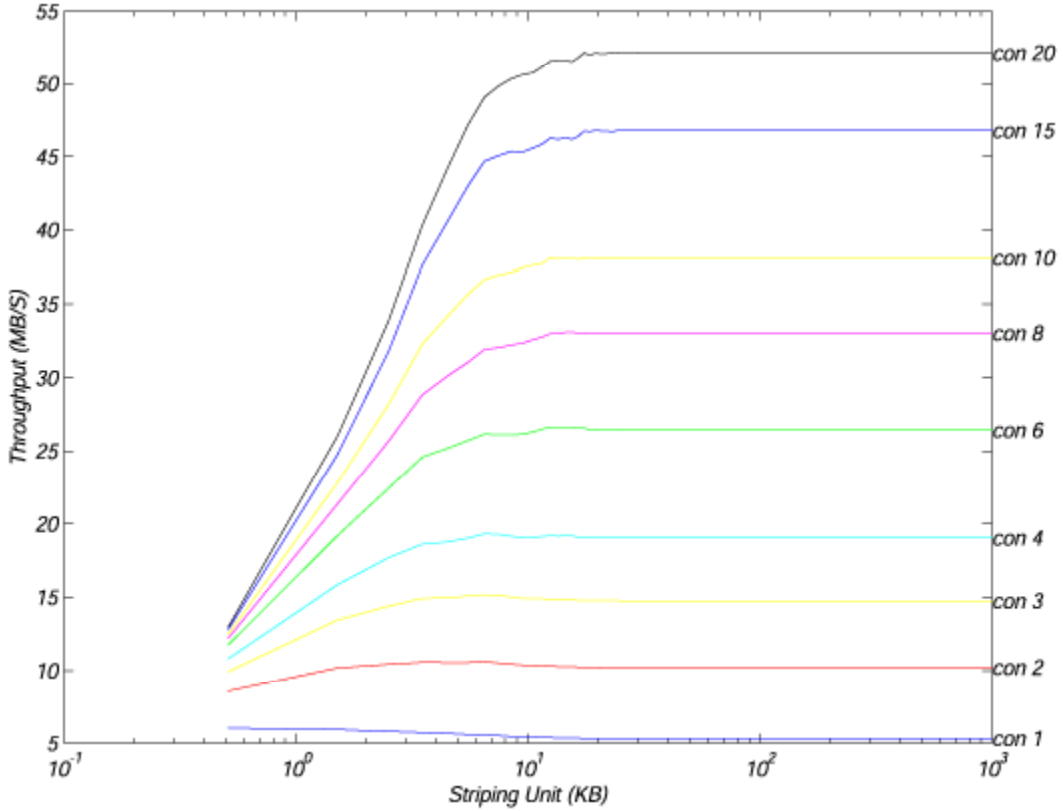
Implications for Probe-based Storage Arrays

- Conventional wisdom:
  - High concurrency, large stripe size
  - Low concurrency, small stripe size

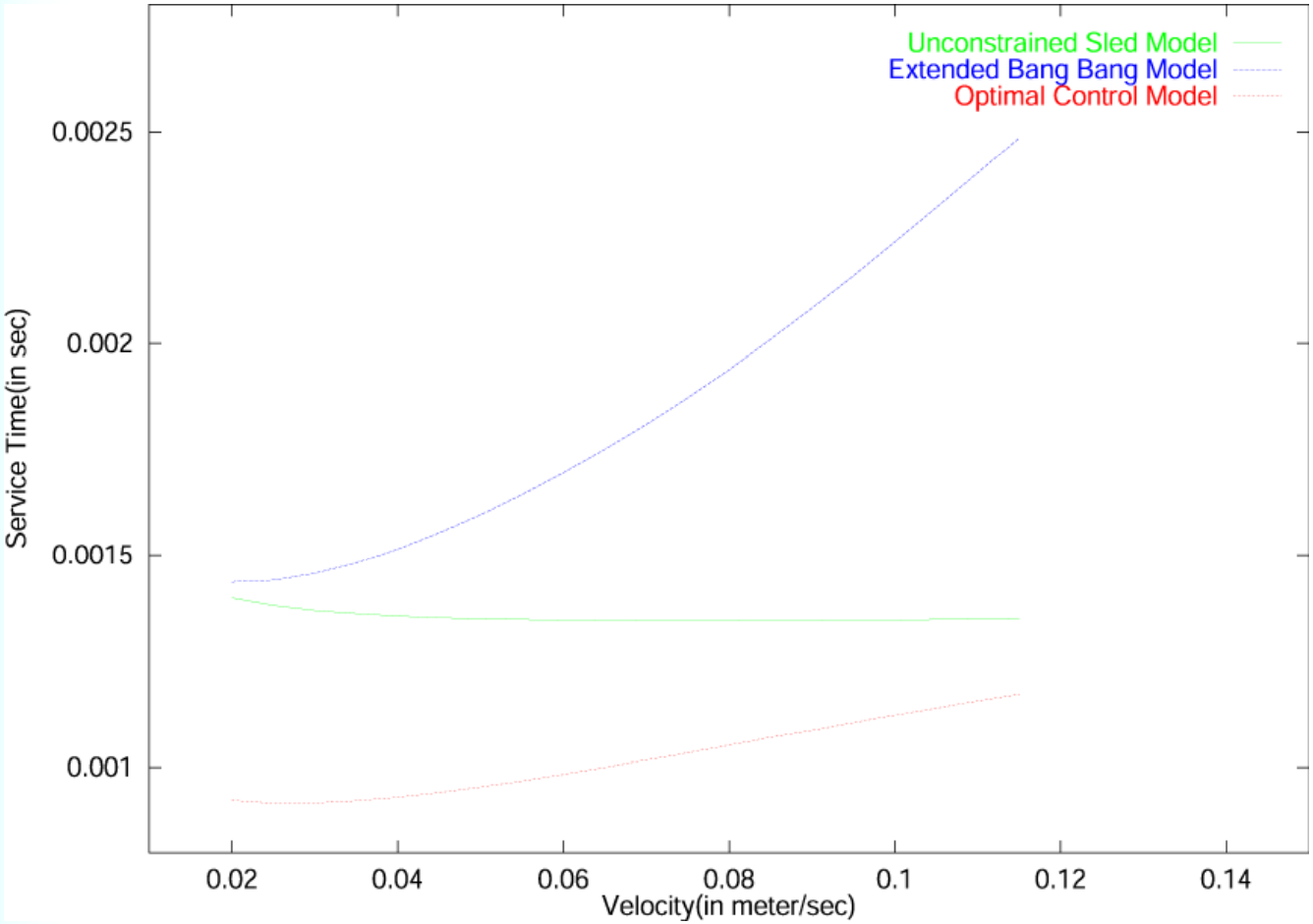
Concurrency, 1 Sled, exp(4KB)



Concurrency, 20 Sleds, exp(4KB)



Model Sensitivity Example



Conclusions

- We don’t yet know the “right” model, but
- We have a reasonable performance range
- Seek/transfer time ratio has significant implications for system design

Acknowledgements

- Katherine Pu Yang
  - Spring model
- Miriam Sivan-Zimet
  - Probe-based storage arrays
- See www.cse.ucsc.edu/stargroup