Simulating MicroElectroMechanical Systems

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Overview

- Simulation: motivations and approaches
- Introducing SUGAR
- Using SUGAR
- Ongoing work
- Conclusion

Simulation: What?

- Process simulation (technology CAD)
- Device simulation
- System simulation

Simulation: Why?

- Test “what if” ideas and initial designs
- Design verification, fine tuning, and parasitic discovery
- Different objectives mean different speed and accuracy requirements

Simulation: How?

- Solve continuum equations (finite elements, finite differences, boundary elements)
- Solve simplified equations of beam and plate theory (finite elements, etc)
- Solve network equations (e.g. modified nodal analysis)
- These approaches are not mutually exclusive!

SUGAR: System simulation

Goal: “Be SPICE to the MEMS world”

- Fast enough for early design stages
- Simple enough to attract users
- Capable of simulating interesting coupled physics

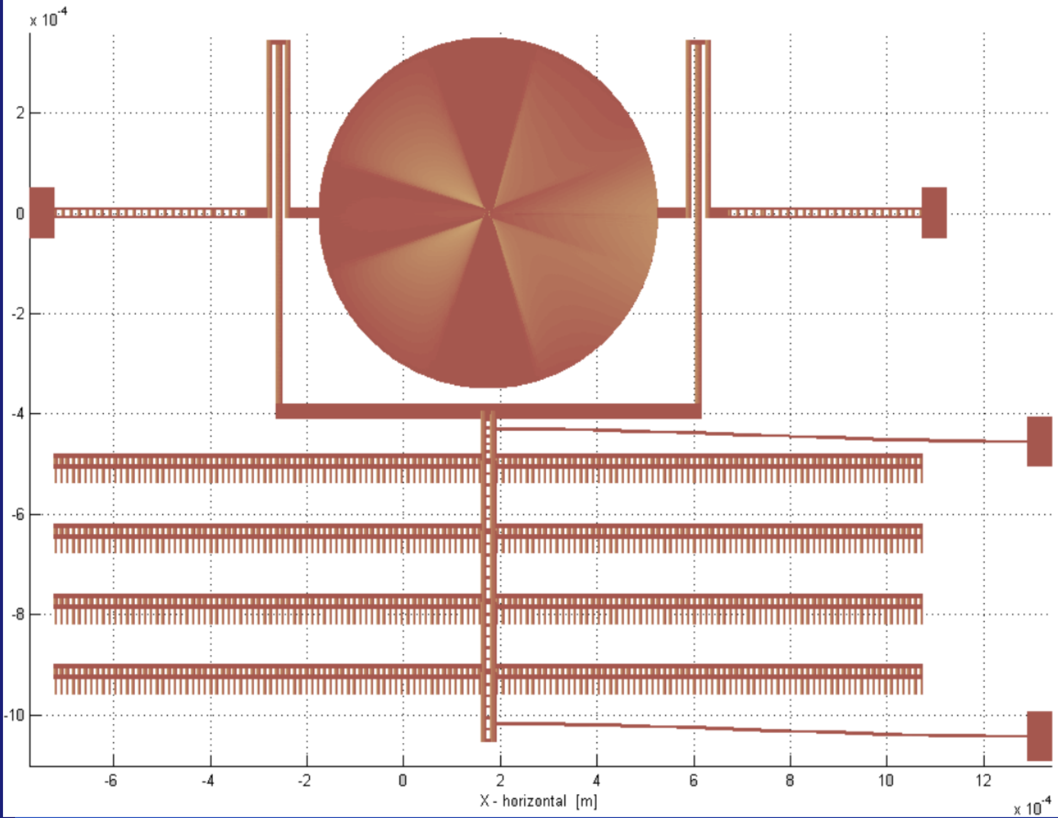
SUGAR group

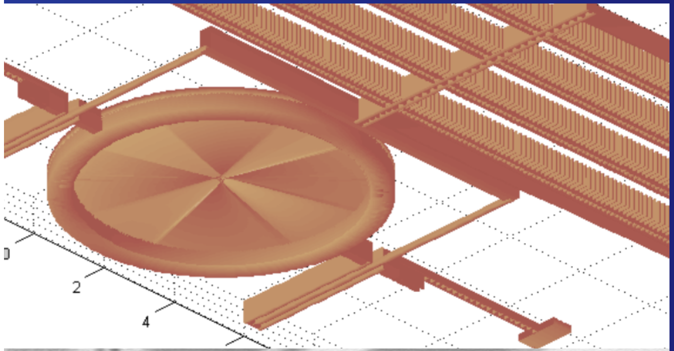
Faculty	Grad students	Undergrads
A. Agogino	D. Bindel	W. Kao
Z. Bai	J.V. Clark	A. Kuo
J. Demmel	D. Garmire	E. Zhu
S. Govindjee	B. Jamshidi	
M. Gu	R. Kamalian	
K.S.J. Pister	S. Lakshmin	
	J. Nie	
	N. Zhou	

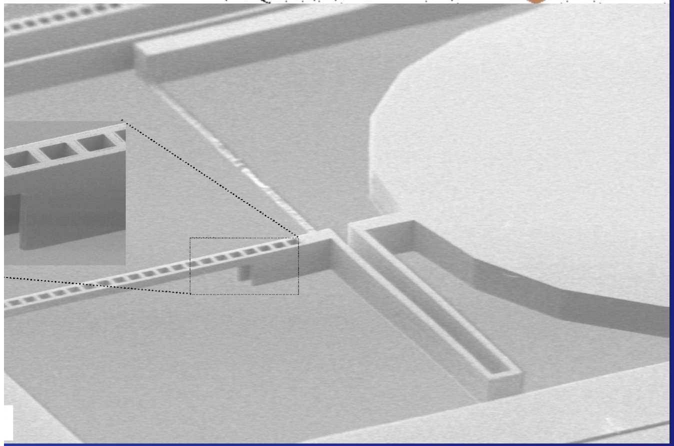
Related work

- Nodas from CMU
- Coventorware
- SPICE, CADENCE, HDL-A, ...
- ANSYS, ABAQUS, FEAP, ...

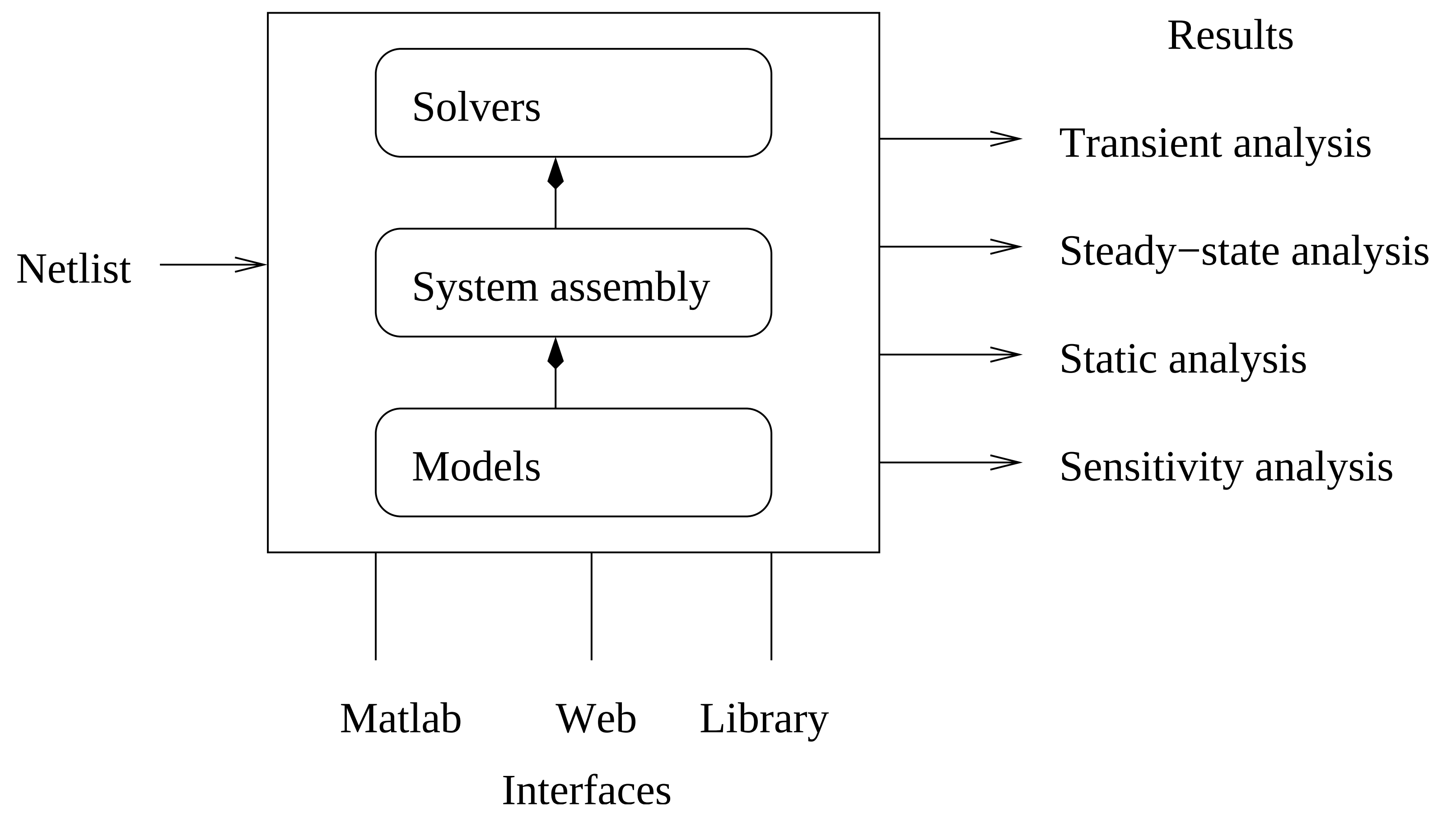
What can we model?







SUGAR architecture



Netlist syntax

```
mybeam beam2d p1 [A B] [l=100u w=2u]
```

- `mybeam` is the element name (optional)
- `beam2d` specifies the 2-d beam model
- `p1` specifies the properties of the POLY1 MUMPS layer
- `A` and `B` are the beam end-nodes
- `[l=100u w=2u]` specifies the length (100 microns) and width (2 microns).

Parameterization

```
param nfingers = 10
```

- `nfingers` can be set by user at load time
- If no value explicitly provided, use ten fingers

Subnets and heirarchical design

- *Subnets* are parameterized components
- Subnet calls look like built-in model calls
- Matches design heirarchies
- Can put commonly-used subnets in a library

Subnet example

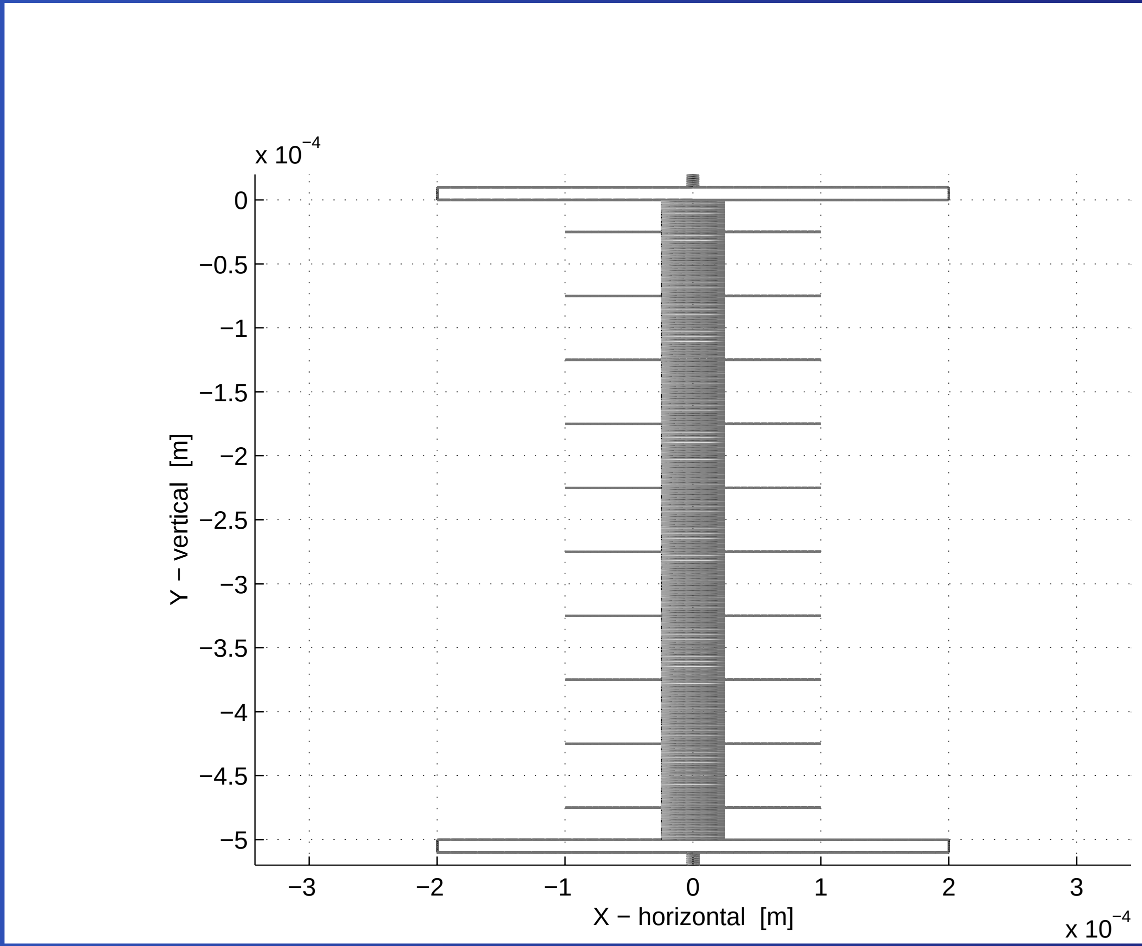
```
subnet XMass [A B] [finger_len=*]
[
  b1 beam3d parent [A  b1] [l=25u        w=50u
                            h=6u oz=-deg(90)]
  b2 beam3d parent [b1 B ] [l=25u        w=50u
                            h=6u oz=-deg(90)]
  b3 beam3d parent [b1 b2] [l=finger_len w=2u
                            h=6u oz= deg(0) ]
  b4 beam3d parent [b1 b3] [l=finger_len w=2u
                            h=6u oz=deg(180)]
]
```

Arrays

```
XSusp p1 [c(1)] [susp_len=200u]
for k=1:nfingers [
  mass(k) XMass p1 [c(k) c(k+1)] [finger_len=100u]
]
XSusp p1 [c(11)] [susp_len=200u oz=pi]
```

- Suspensions at either end
- `nfingers` comb-finger units as defined above

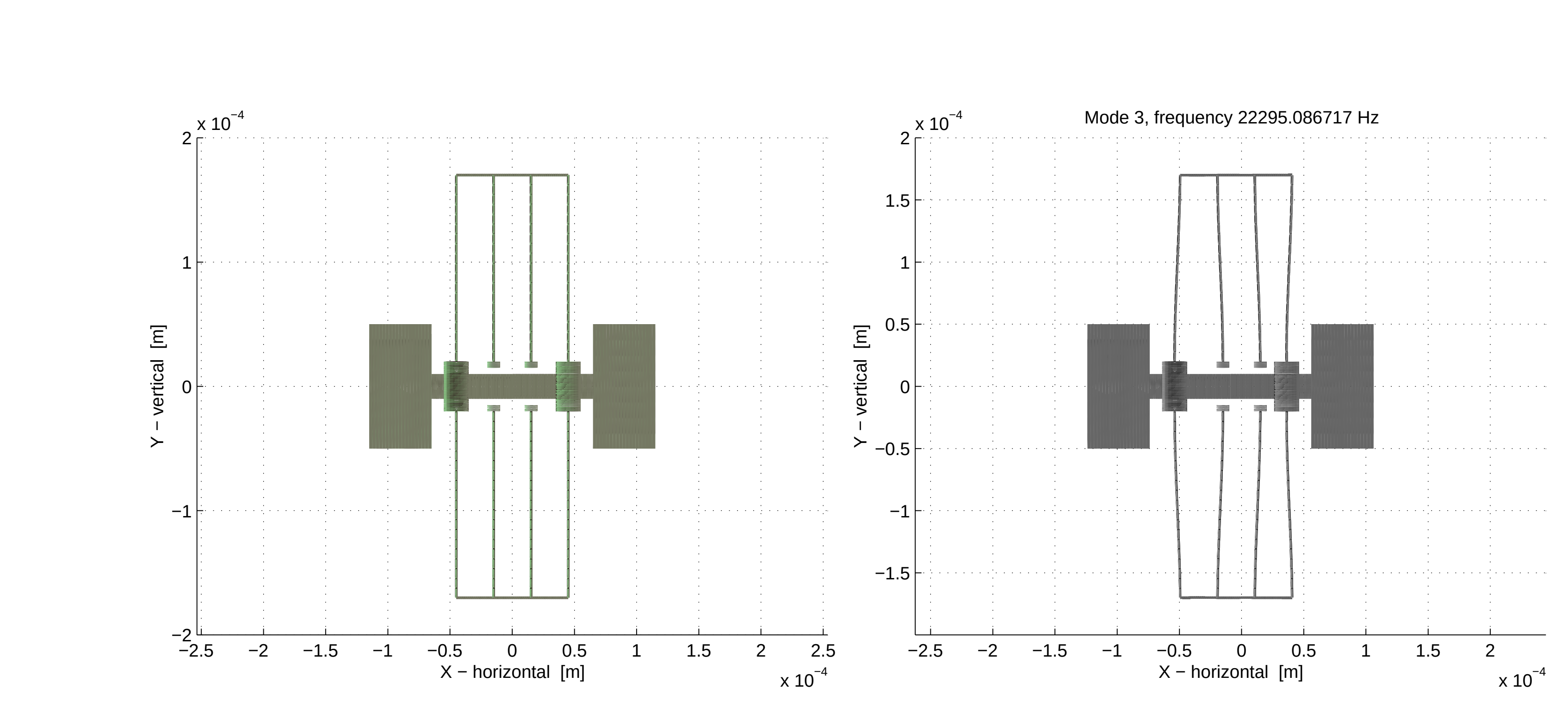
Result: simplified ADXL-50



Types of analysis

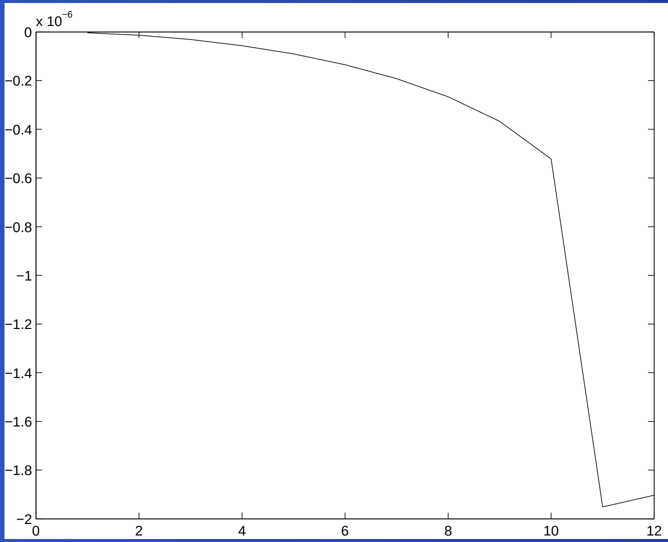
- Transient response
- Static equilibrium (DC analysis)
- Steady-state response
- Mode shape determination

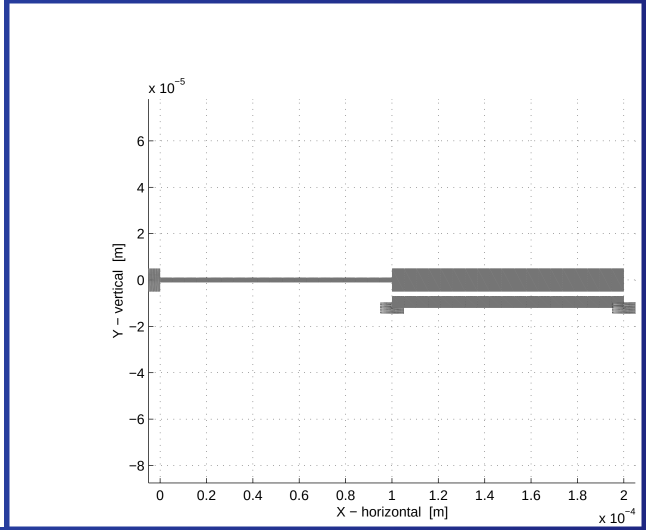
Example: Modal analysis



Dogbone suspension for comb drive resonator

Using the Matlab interface





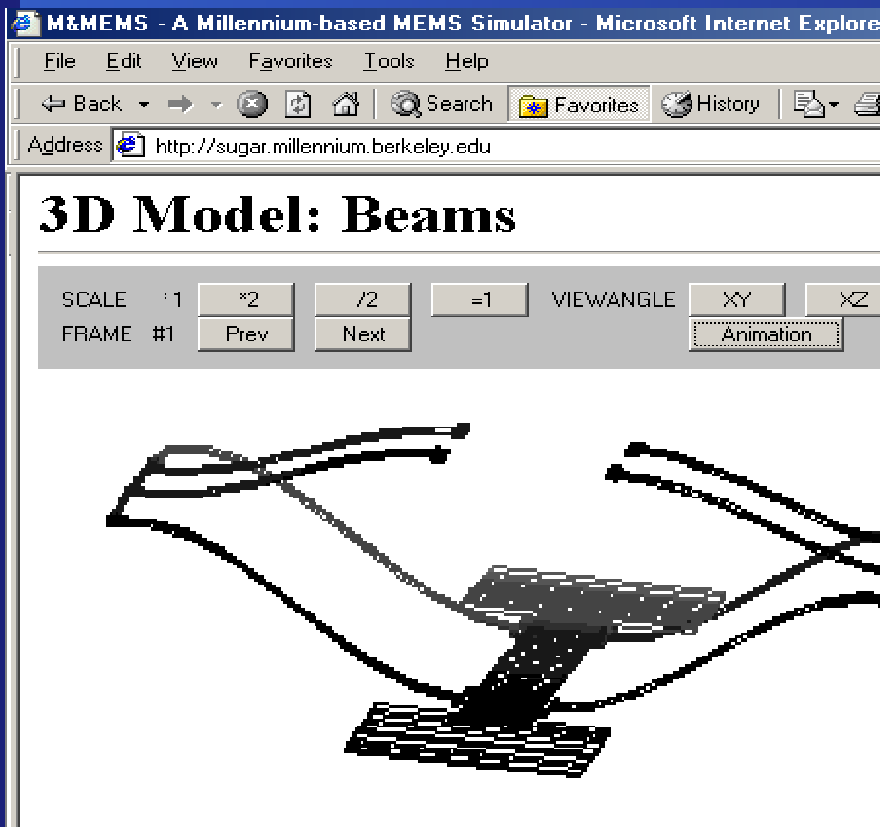

```
dq = [];
for k=1:12
  param.V = k;
  net = cho_load('beamgap2b.net', param);
  dq = cho_dc(net, dq);
  tip(k) = cho_dq_view(dq, net, 'c', 'y');
end
```

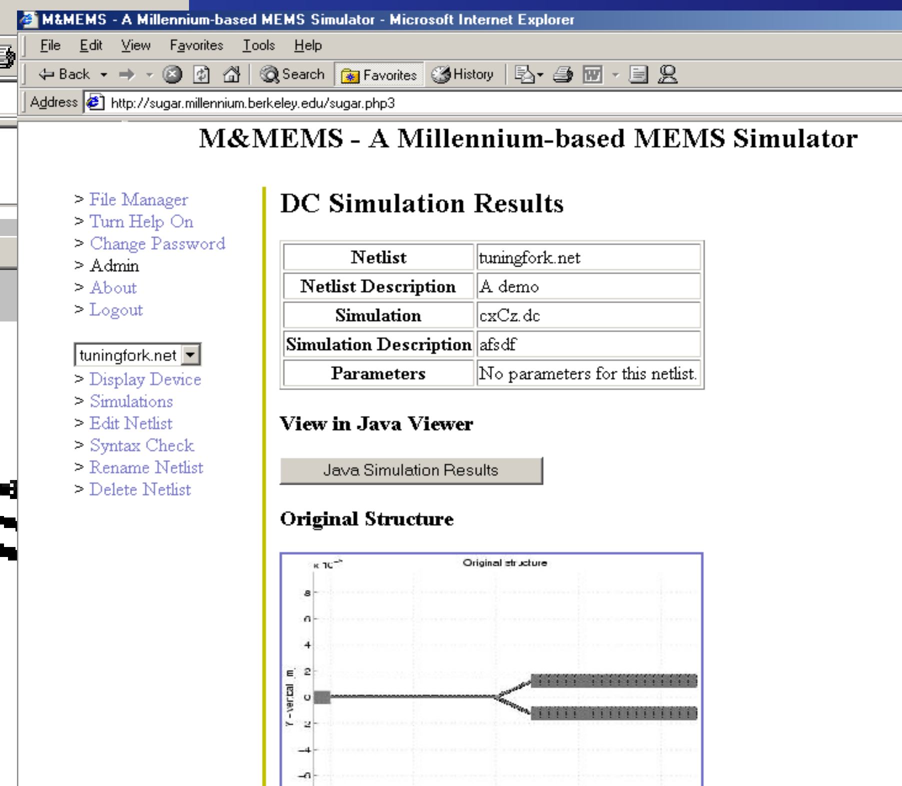
SUGAR 3.0

- SUGAR 2.0: Matlab core, C add-ons
- SUGAR 3.0: C core, Matlab interfaces
- Release target: some time this month?
- Web service using 3.0 should be more robust
- Can use SUGAR 3.0 even without Matlab

M&MEMS: SUGAR on the Web

http://sugar.millennium.berkeley.edu/





M&MEMS: Pros and cons

- Pro: Only need a web browser with Java
- Pro: Fixes can be applied rapidly
- Pro: Potential parallelism
- Con: Less flexibility than Matlab environment
- Con: Too many failure points in initial version
- Con: Poor response time in initial version

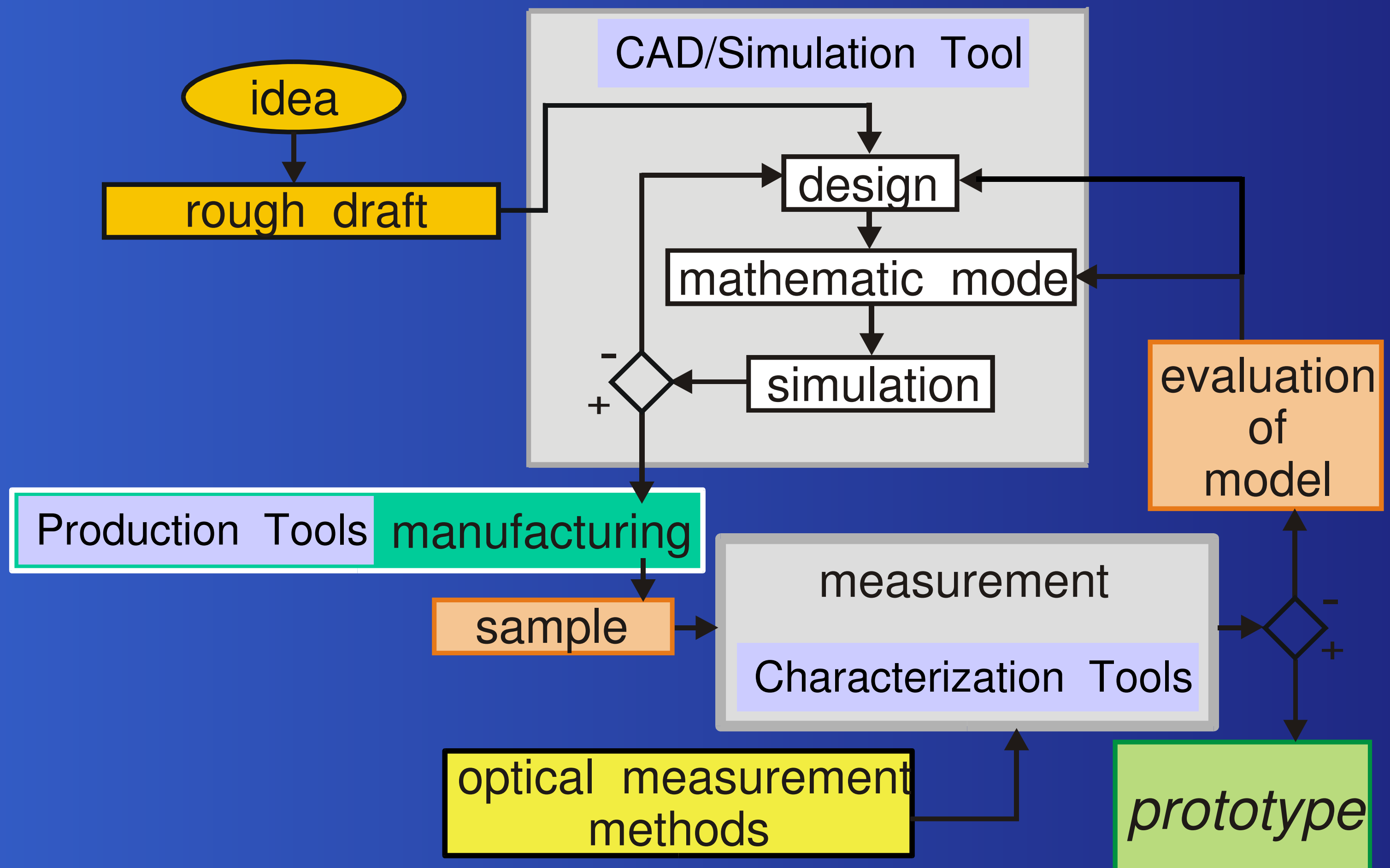
M&MEMS: Lessons from EE245

- Used in Introduction to MEMS course, Fall 01 (Pister)
- Problems with both hardware and software
- Matlab too heavyweight in this environment
- Students used it anyhow!

Matisse: Integrating measurement

- Set of optical measurement tools
- Make available on the web as a “virtual lab”
- Matisse team: R. Kant, R. Muller, C. Rembe, M. Young

Matisse: Closing the design loop



Design synthesis and optimization

- Genetic algorithms to evolve new designs
- Specializing designs from a library
- N. Zhou, B. Zhu, A. Agogino, and K. Pister: "Evolutionary Synthesis of MEMS (Microelectronic Mechanical Systems) Design" (ANNIE 2001). First Runner-up for Novel Smart Engineering System Design Award.

Model reduction

- Used to create macromodels from detailed device simulations
- Also used to reduce large system models
- Need to handle nonlinear effects
- Z. Bai is the local expert on ROM

Improved models

- Geometric nonlinear beams
- Torsion-bending coupling for single-crystal Si
- Contact
- More coupling effects: electrothermal, thermomechanical, electromechanical, ...
- Plates, hinges, other mechanics
- Improved damping models
- Improved thermal models

Improved numerics

- Incorporate current technology: SuperLU, DASSL and IDA, etc.
- Improved time integration
- Scaling and improved error measures
- Continuation for improved static analysis and study of bifurcations
- Sensitivity analysis
- Incorporate parallel techniques where appropriate

Conclusions

- SUGAR is already a useful design / education tool
- Lots of activity to extend SUGAR and improve robustness
- Friendly users appreciated!