

ICCAD Workshop on Variability Modeling and Characterization
Nov. 5, 2015

NEEDS:

Science, Circuits, and Systems

Mark Lundstrom
Purdue University
MIT, U.C. Berkeley, Stanford



NEEDS

Goal:

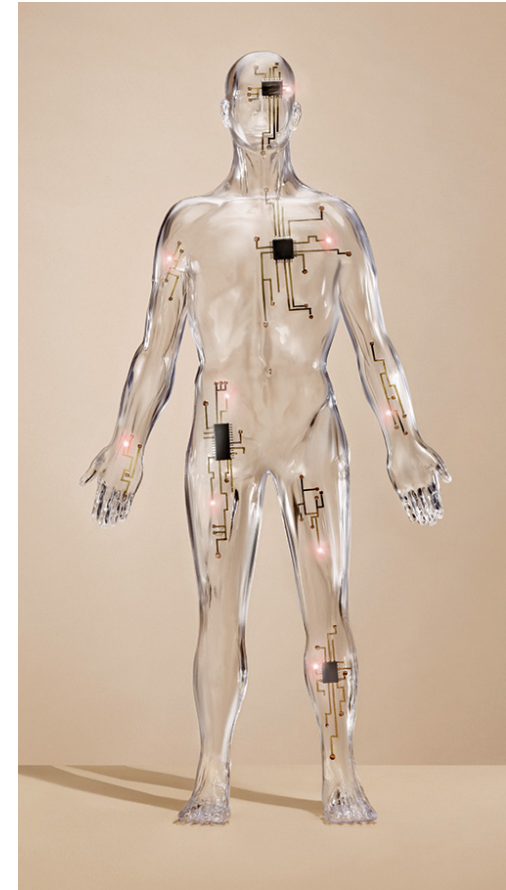
To advance the science of nanodevices and enable new applications.

Focus:

- 1) Physics-based compact models for emerging devices.
- 2) Infrastructure to support the NEEDS team and the broader community.

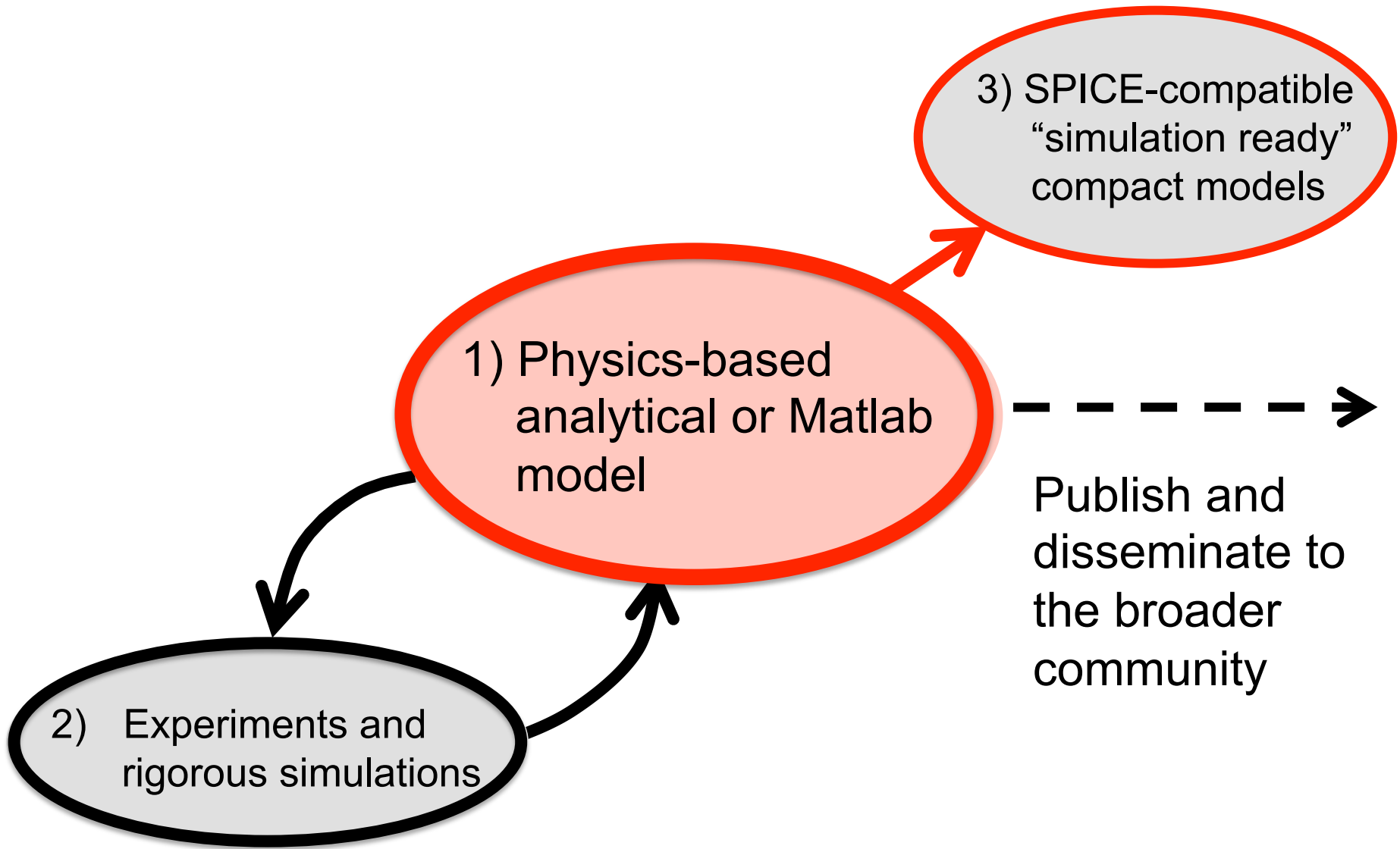
Electronics is in transition

- We Will End Disability by Becoming Cyborgs
- Robots Will Pave the Way to Mars
- Make Your Own World With Programmable Matter
- Digital Actors Go Beyond the Uncanny Valley
- The Rise of the Personal Power Plant
- Wearable Computers Will Transform Language
- Driverless Cars: Optional by 2024, Mandatory by 2044
- So, Where Are My Robot Servants?



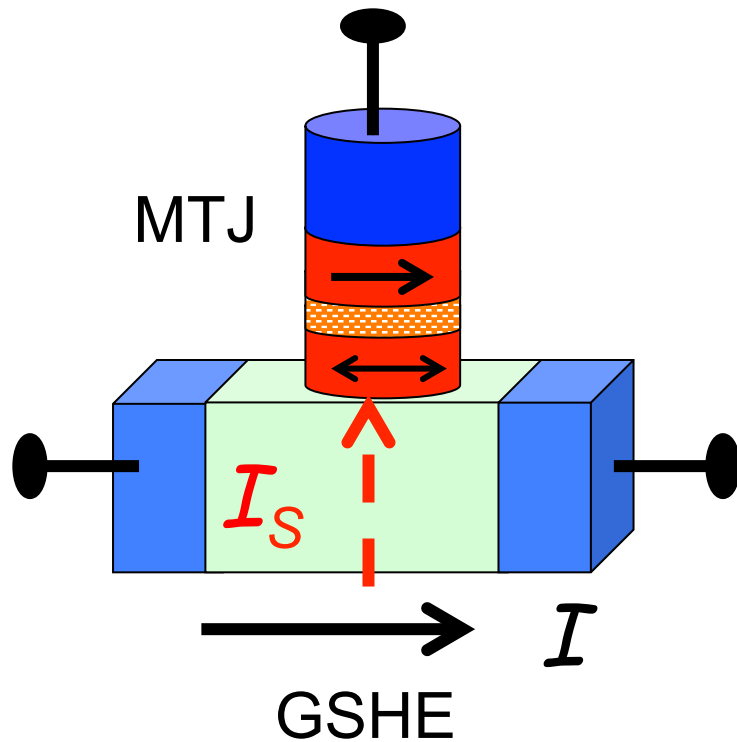
“The Future We Deserve”, *IEEE Spectrum*, Jan. 2015.

systems and applications



nanoscience of materials and devices

NEEDS device science: spintronics



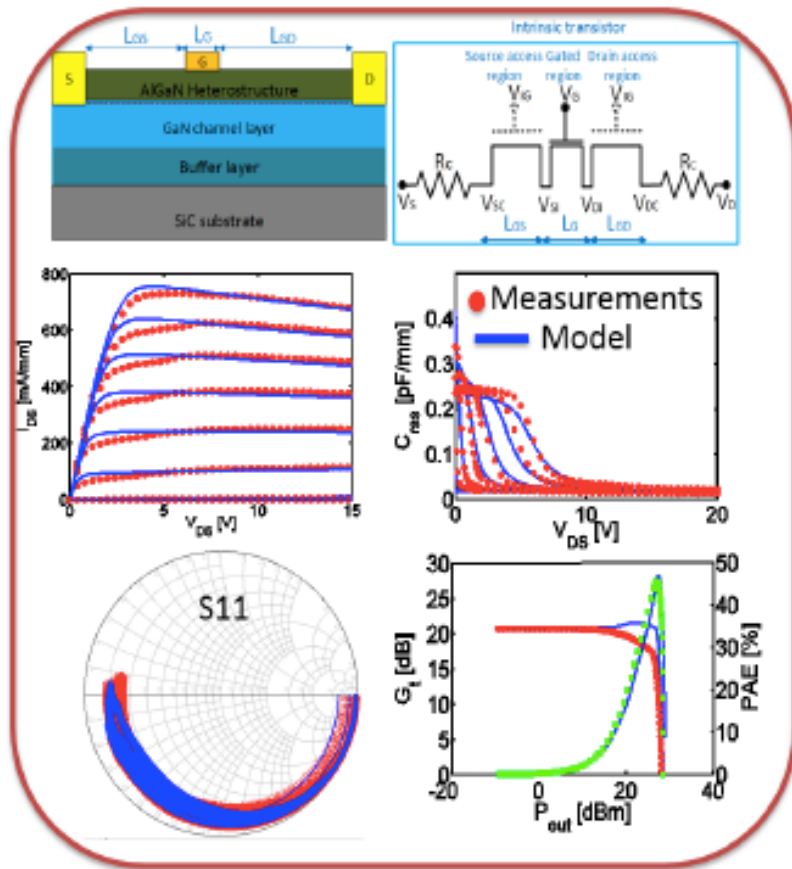
$$\begin{Bmatrix} V \\ \vec{V}_s \end{Bmatrix}, \begin{Bmatrix} I \\ \vec{I}_s \end{Bmatrix}$$

Elemental Modules

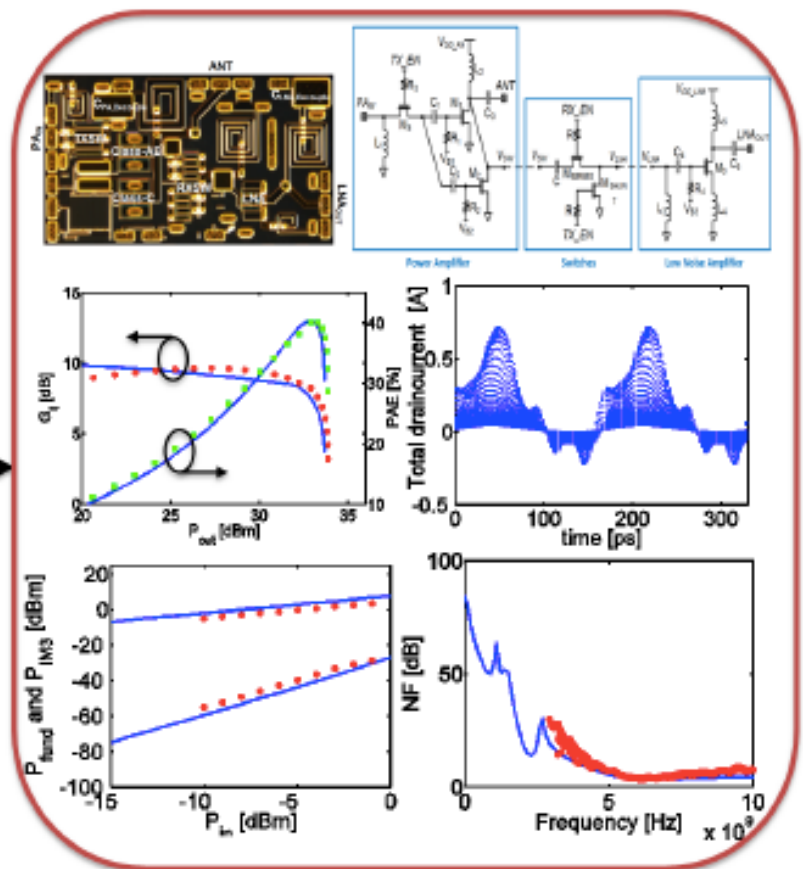
Transport Modules	<p>1 → NM → 2</p> <p>Non-Magnet (Cu, Si, graphene)</p>	<p>1 → FM → 2</p> <p>Ferromagnet (CoFeB, NiFe)</p>	<p>1 → F N → 2</p> <p>Ferromagnet/Non-Magnet Interface (NiFe Cu)</p>	<p>1 → MTJ → 2</p> <p>Magnetic Tunnel Junction</p>
	<p>1 → RSO → 2</p> <p>Rashba Spin-Orbit (GaAs)</p>	<p>1 → GSHE → 2</p> <p>Giant Spin Hall Effect (Pt, W, Ta)</p>	<p>1 → TI → 2</p> <p>Topological Insulator (Bi₂Se₃)</p>	<p>SPIN PUMP</p> <p>Spin Pumping</p> <p><i>New!</i></p>
Magnetics Modules	<p>$\vec{I}_s, \vec{H} \rightarrow$ LLG $\rightarrow \hat{m}$</p> <p>LLG Solver (magnetization dynamics)</p>	<p>$\hat{m}_1, \hat{m}_2 \rightarrow$ Magnetic Coupling $\rightarrow \vec{H}_{21}, \vec{H}_{12}$</p> <p>Magnetic Coupling (Exchange, Dipolar)</p>	<p>VCMA</p> <p>Voltage Controlled Magnetic Anisotropy</p> <p><i>New!</i></p>	<p>$\vec{I}_s, \vec{H} \rightarrow$ LLG $\rightarrow \hat{m}$</p> <p>Stochastic LLG</p> <p><i>New!</i></p>

NEEDS device science: RF GaN FETS

Device Technology



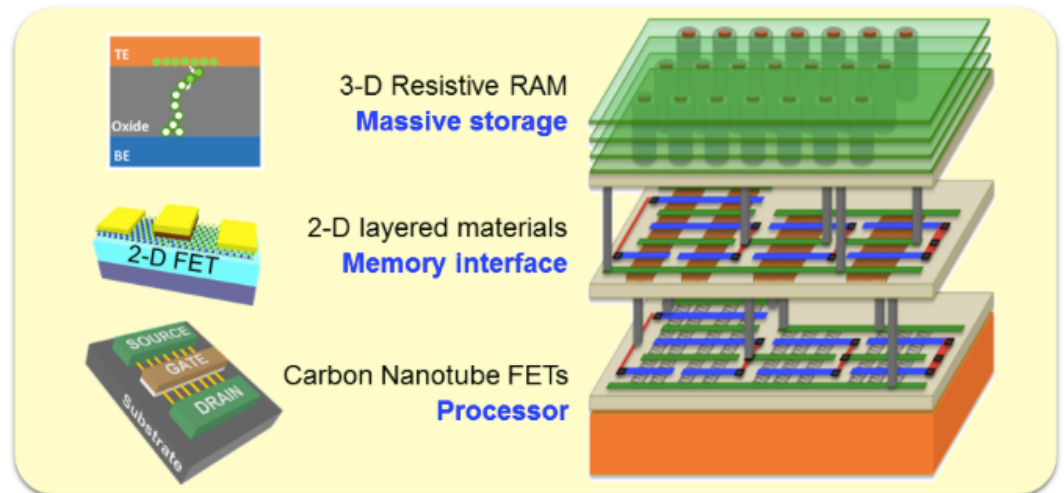
Circuit Design



NEEDS device science: Integrated nanosystems



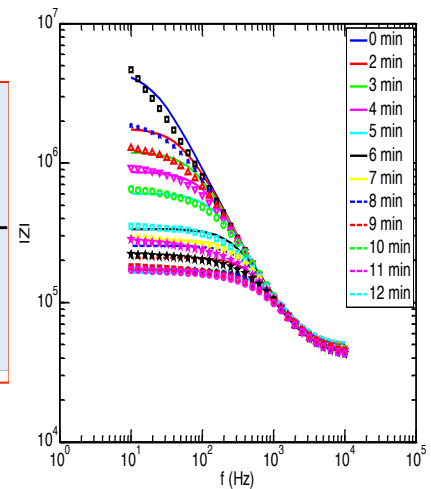
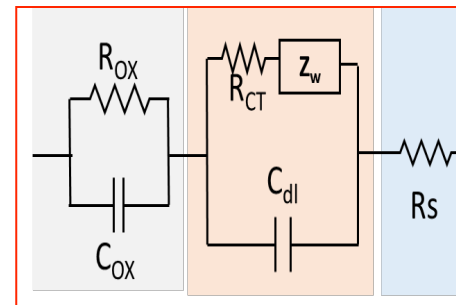
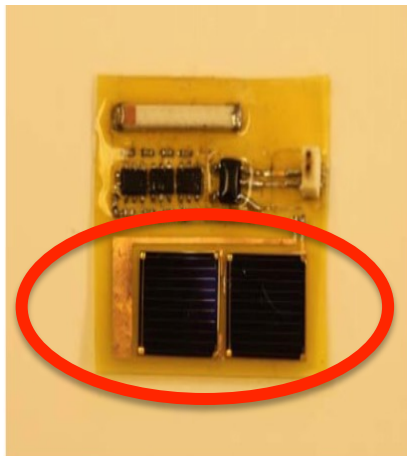
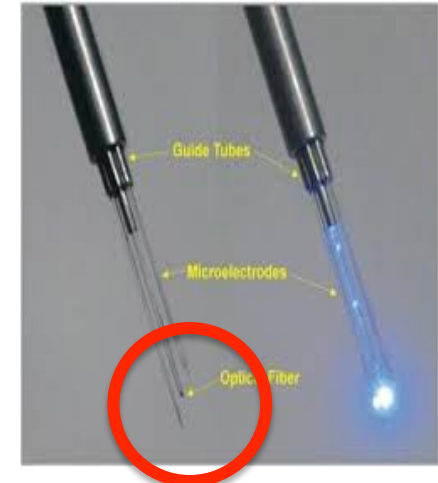
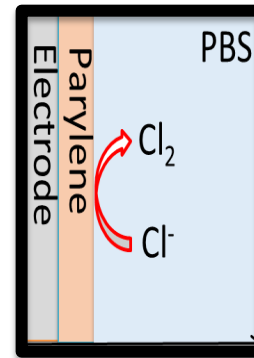
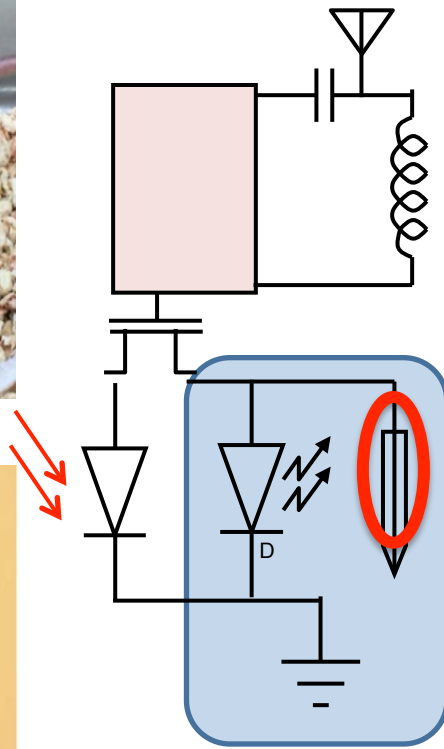
Compact models: essential, but **insufficient alone**



H.S.P. Wong and S. Mitra

(ICCAD 2015 Workshop on Variability Modeling and Characterization)

NEEDS device science: implantable optogenetics



J. Rogers (UIUC), P. Irazoqui, T. Fisher, and M. Alam (Purdue)

Specific Infrastructure Goals

- 1) Develop a suite of open-source, **physics-based** compact models for emerging nanodevices.
- 2) Create **tools and processes** for developing compact models.
- 3) Produce **educational resources** to support 1) and 2).
- 4) Leverage **nanoHUB.org** to engage a broad community of device researchers and designers.



Nano-Engineered Electronic Device Simulation Node

NEEDS has a vision for a new era of electronics that couples the power of billion-transistor CMOS technology with the new capabilities of emerging nano-devices and a charter to create high-quality models and a complete development environment that enables a community of compact model developers.

NEEDS Team: Purdue, MIT, U.C. Berkeley, and Stanford.

NEWEST COMPACT MODEL RELEASE: Optical Ring Filter (ORF) Modspec Compact Model and Non-Faradaic Impedance-based Biosensor Model. [See Compact Models Page](#)

NEEDS announces the public release of [Berkeley MAPP](#), a MATLAB-based platform for prototyping compact models and simulation algorithms.

GET STARTED ON COMPACT MODELING: Take Colin McAndrew's [online workshop](#).



COMPACT MODELS

SPICE-compatible
Verilog-A format
supporting resources



COMPACT MODELS: TOOLS

Tools for developers
including [MAPP](#) & [VALint](#).



COMPACT MODELS: RESOURCES FOR DEVELOPERS

Seminars and tutorials for
developing and publishing
compact models



NANOSCIENCE TO SYSTEMS

Physically-detailed simulations
system level tools



NANOSCIENCE: SEMINARS, COURSES, ETC.

NEEDS Seminars, workshops,
[nanoHUB-U](#) and more

1) physics-based compact models

Virtual source transistor models for:

Si
Graphene
GaN – RF and high-voltage
CNTFETs
etc.

Novel transistors:

2D TMD
FeFETs
TFETs

Memory devices:

RRAM
CBRAM
phase change

Spintronic devices

TMJ, etc.

Optical devices:

VCSELs
Si-based modulators

MEMS resonators:

released
unreleased

Energy devices:

solar cells
thermoelectric devices

biosensor models for:

FET-based sensing
impedimetric sensing
mechanical sensing

publish your model with NEEDS



NEEDS

NANO-ENGINEERED ELECTRONIC
DEVICE SIMULATION NODE

NEEDS HOME

ABOUT US

RESOURCES

CONTACT US

NEEDS TEAM

For Developers

[Submit Compact Model >> Start Here](#) 

Resources for deploying NEEDS compact models:

[Checklist for Submitting a NEEDS Compact Model \(33 Kb\)](#)

[Detailed Instructions for Submitting a NEEDS Compact Model \(45 Kb\)](#)

[Compact Model Council's recommendations for versioning compact models](#)

[NEEDS-modified Compact Model Council Standard license for compact models \(2 Kb\)](#)

[Tips for Verilog-A NEEDS Compact Model Release – Lessons Learned from MVS 1.0.0](#)
by Shaloo Rakheja

[Guidelines for Writing NEEDS-certified Verilog-A Compact Models](#)
by T. Wang and J. Roychowdhury

[Compact Model Council Compact Model QA Specification](#)

General resources for compact model developers:

[How to Write, Develop and Implement a Real Compact Model](#)
A Hands-on Workshop by Colin McAndrew

[Basics of Compact Model Development](#)
by Sivakumar Mudanai

[How Really Smart People Can Write Really Dumb Models](#)
by Colin McAndrew

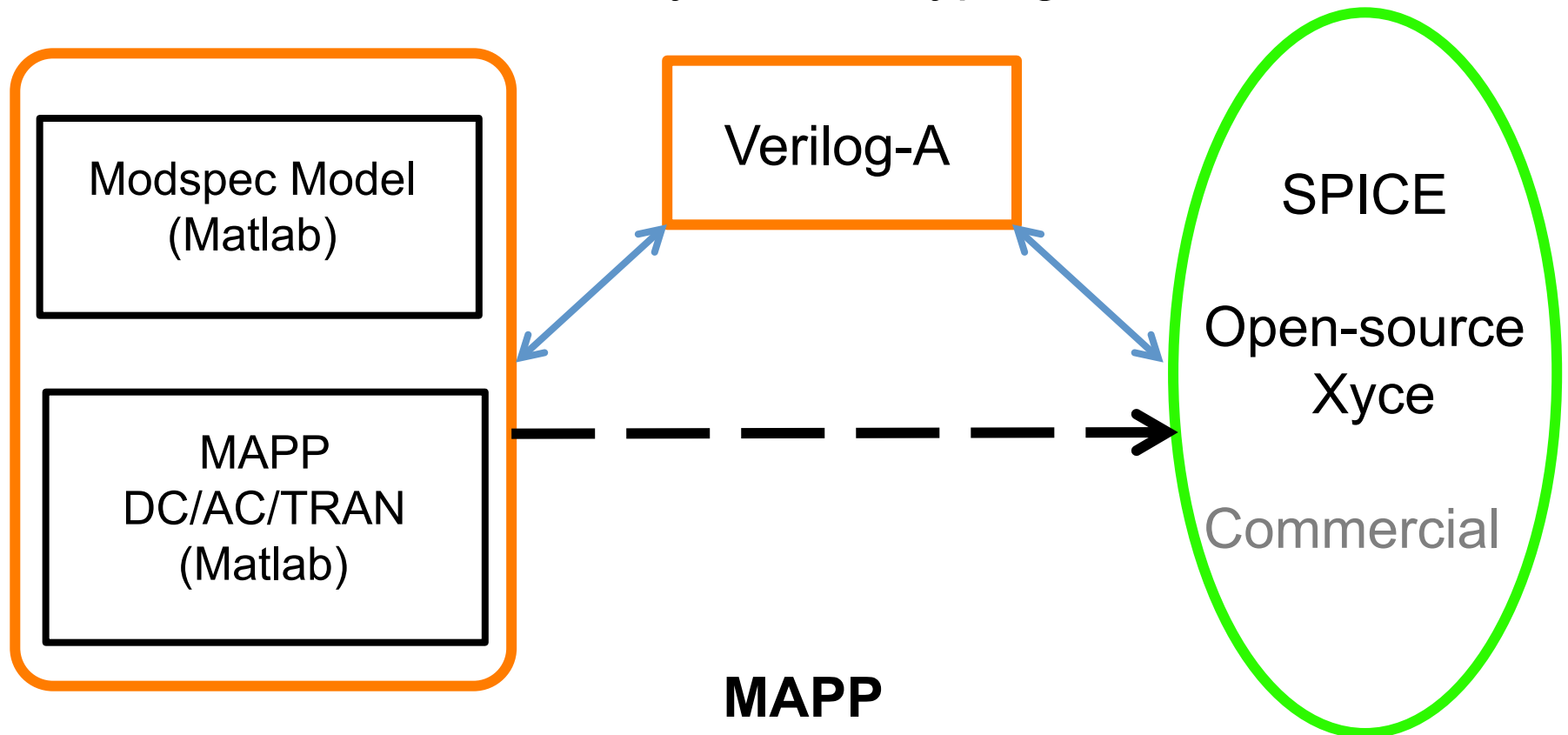
Case Studies in Compact Modeling

[The MVS Nanotransistor Model: A Case Study in Compact Modeling](#)
by Shaloo Rakheja

digital object identifiers (DOI's)
Thompson-Reuters Web-of-Science

Goal 2: tools for developing compact models

Model and Analysis Prototyping Platform



Led by Jaijeet Roychowdhury, U.C. Berkeley

First public release: Dec. 2014

VALint (Xufeng Wang, Coram, and McAndrew)

VALint: the NEEDS Verilog-A Checker (BETA) [Settings] [X] Terminate [▶] Keep for later

New Examples... Open... Save As... Close... Pretty Print Check Syntax

masterTest.va (original)

```
55 MPRcc( fc      , 0.9      , ""      , 0.0, 0.99, "depletion capacitance linearization factor")
56 MPRco( cj0    , 1.0e-12, "F"    , 0.0, inf, "zero-bias depletion capacitance")
57 MPRoo( pj     , 0.9     , "V"    , 0.0, inf, "built-in potential for cj")
58
59
60 analog begin : vaTest1Model
61
62   real vj, qjCalc, cjDdx, cjCalc;
63
64   vj = V(ref); // referenced to ground, no branch defined, inconsistent indenting
65   if (vj > fc*pj) // missing begin/end, trailing space
66     cjCalc = cj0*pow(1-fc, -mj); // 1 should be 1.0
67   else // missing begin/end
68     cjCalc = cj0*pow(1-vj/pj, -mj); // 1 should be 1.0
69   qjCalc= cj0*qj(vj, pj, mj, fc, -1); // 1 should be 1.0, unaligned on =
70   cjDdx= ddx(qjCalc, V(ref)); // should not use except for operating point information, unaligned on =
71
72   I(n1) <+ -ddt(qjCalc); // referenced to ground, no branch defined
73   I(n2) <+ -ddt(vj)*cjCalc; // referenced to ground, no branch defined, should use ddt(q)
74   I(n3) <+ -ddt(vj)*cjDdx; // referenced to ground, no branch defined, should use ddt(q)
75
76 end // analog
77 endmodule
78
```

a lint for Verilog-A code

- Based on ADMS
- Checks for “bad practice”
- “Pretty prints” Verilog-A codes.
- Public beta release: 10/29/15

Type	Line	Message
license		Missing NEEDS license
warning	19	Variables inside macros
error	64	Referencing to global ground
warning	66	INT 1 and REAL fc type
warning	68	INT 1 and REAL vj type
warning	65	IF statement lacks "begin"
warning	67	ELSE statement lacks "begin"
error	70	Referencing to global ground node is forbidden!
error	70	The use of ddx() in calculation is forbidden!

PUQ: Open source tools for UQ



[home](#) | [search](#) | [documentation](#) »

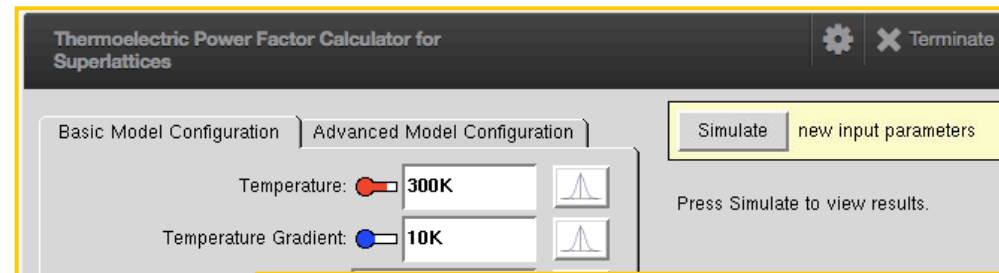
PUQ – PRISM UNCERTAINTY QUANTIFICATION FRAMEWORK

Contents:

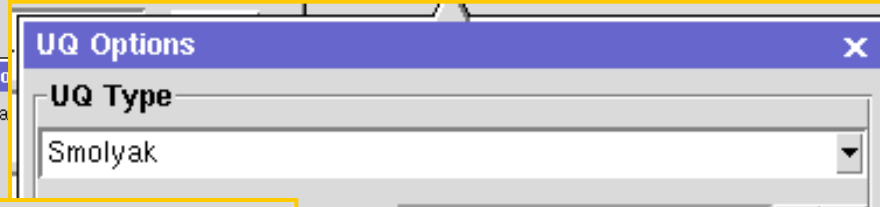
- [Overview](#)
 - [Goals](#)
 - [Future Plans](#)
- [User's Guide and Tutorial](#)
 - [Getting Started](#)
 - [Requirements](#)
 - [Monte Carlo Sampling](#)
 - [Extending the Sample Size](#)
 - [Latin Hypercube Sampling](#)
 - [Smolyak Sparse Grid Algorithm](#)
 - [Modifying Smolyak Sweeps](#)
 - [Extending](#)
 - [Modifying Parameters & Reusing Response Surfaces](#)
 - [Calibration of Input Variables](#)
 - [Using PUQ for Calibration](#)
 - [Example](#)

<http://c-primed.github.io/puq/>

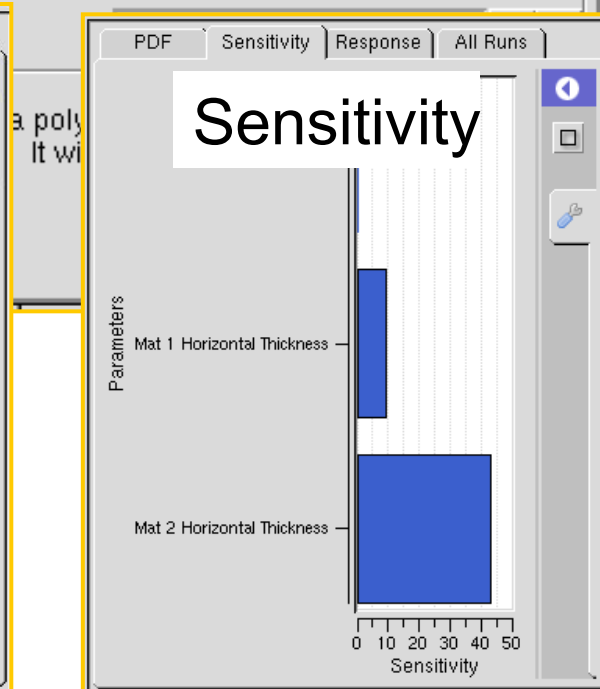
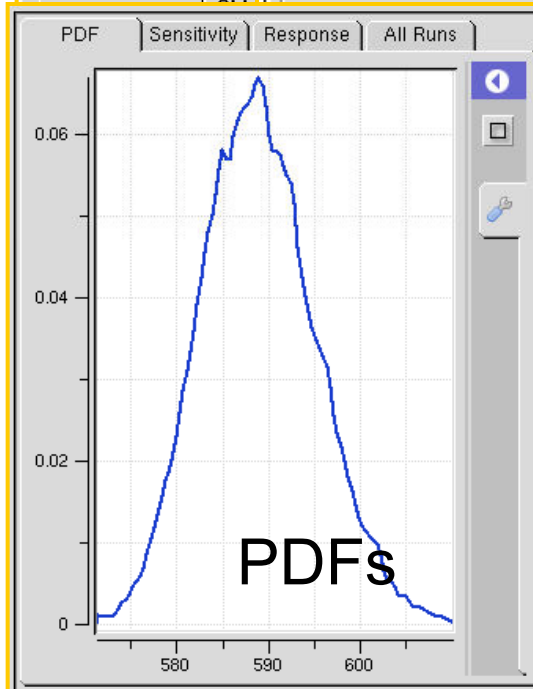
Automatic UQ in nanoHUB.org



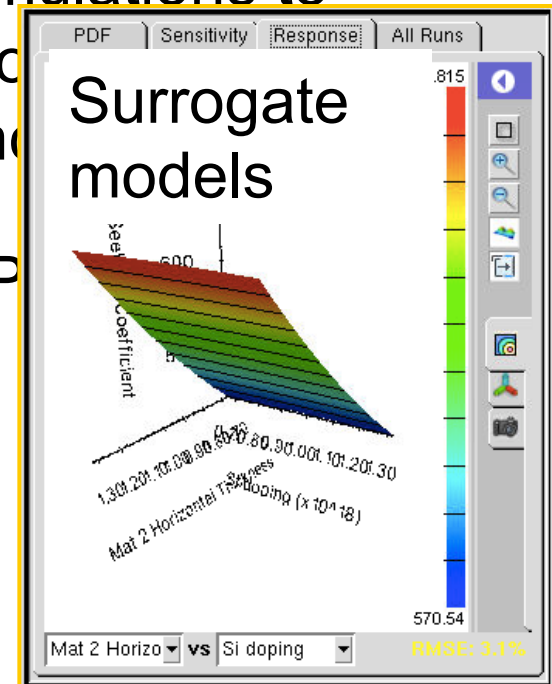
Inputs can be specified as single values or distributions



Run multiple simulations to



pro
unc



education for 21st Century Electronics



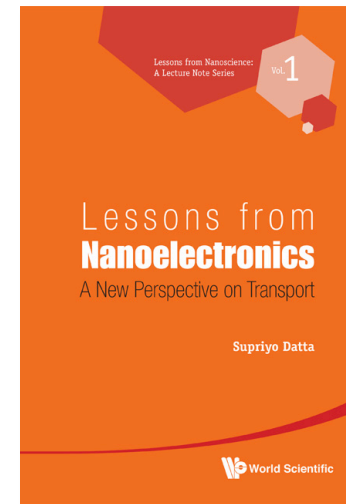
“SEEC” 1960’s

Richard Adler, MIT

web.mit.edu/klund/www/books/seec.html

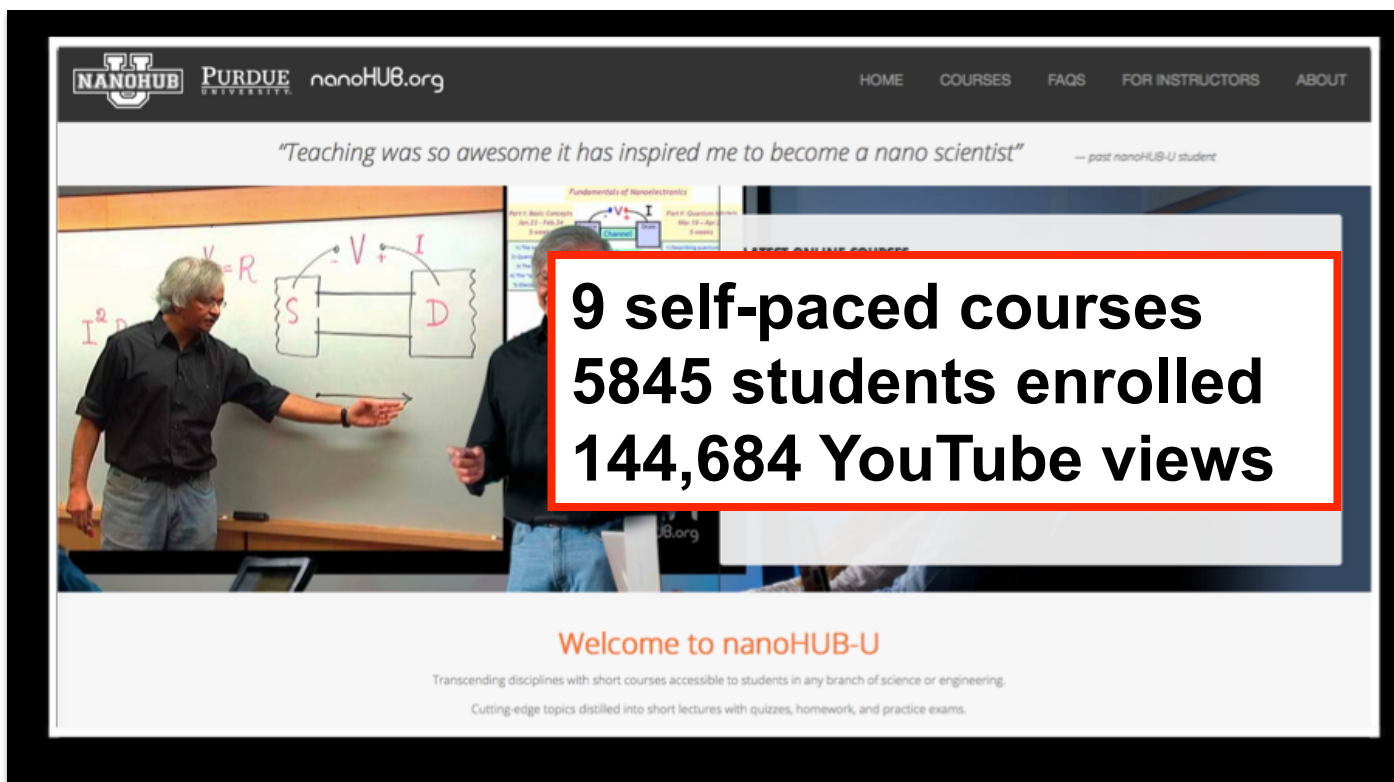


<http://nanohub.org/u>



nanohub.org/wiki/LessonsfromNanoscience 17

nanoHUB.org/u



9 self-paced courses
5845 students enrolled
144,684 YouTube views

Welcome to nanoHUB-U

Transcending disciplines with short courses accessible to students in any branch of science or engineering.
Cutting-edge topics distilled into short lectures with quizzes, homework, and practice exams.

12

Courses Offered

~7,000

Learners

1,000

Universities

166

Companies

91

Countries



PurdueX

nanohub.org/u



Back to schools and partners

<p>VERIFIED</p>	<p>VERIFIED</p>	<p>VERIFIED</p>
<p>PurdueX nano530x</p> <p>Nanotechnology: Fundamentals of Nanotransistors</p> <p>Upcoming Starts: January 25, 2016</p>	<p>PurdueX nano535x</p> <p>Principles of Electronic Biosensors</p> <p>Upcoming Starts: March 1, 2016</p>	<p>PurdueX nano525x</p> <p>Introduction to Bioelectricity</p> <p>Current Starts: August 24, 2015</p>
<p>VERIFIED</p>	<p>VERIFIED</p>	<p>VERIFIED</p>
<p>PurdueX nano521x</p> <p>Fundamentals of Nanoelectronics, Part B: Quantum Transport</p> <p>Current Starts: October 8, 2015</p>	<p>PurdueX nano520x</p> <p>Fundamentals of Nanoelectronics: Basic Concepts</p> <p>Archived Starts: March 26, 2015</p>	<p>PurdueX nano515x</p> <p>Organic Electronic Devices</p> <p>Archived Starts: February 12, 2015</p>

Fundamentals of Nanoelectronics:

5447 students
20 USA
22% India
129 countries
Ave. age. 26

“This course challenged me to think deeply about things I had never been exposed to before.”

“I may start a new career as a result of this course.”

edX.org

The screenshot shows the edX.org website interface. At the top, there is a navigation bar with the edX logo, links for 'Courses', 'How It Works', 'Schools & Partners', and 'About', a search bar with the text 'I want to learn about...', and buttons for 'Sign In' and 'Register'. The main content area features a course card for 'Fundamentals of Nanoelectronics, Part B: Quantum Transport' by Purdue University. The card includes a video player thumbnail, a description: 'Explore quantum transport in nanoscale devices and spintronics in this introductory nanotechnology course.', a quote from a student: '"This MOOC is one of the best. Exceptional in all regards." - Student from Part A', and a green 'Enroll Now' button. To the right of the course card, there is a 'Join Now' section with the text 'Started on October 8, 2015' and a checkbox for 'I would like to receive email from Purdue University and learn about its other programs.' Below the course card, there is an 'About this course' section with a 0/5 star rating and a 'See more' link. To the right of this section is a table of course details: Length: 8 weeks, Effort: 5 - 6 hours/week, Price: FREE (Add a Verified Certificate for \$50), Institution: PurdueX, Subject: Electronics, and Level: Intermediate. At the bottom of the course card, there is a 'What you'll learn' section with a bullet point: 'Introduction to the Tight-binding Method'.

4
Courses Offered

~24,000
Learners

884
Universities

~25%
Industry

141
Countries



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needs.nanoHUB.org



COMPACT MODELS

SPICE-compatible
Verilog-A format
supporting resources



COMPACT MODELS:
TOOLS

Tools for developers
including **MAPP** & **VALint**.



COMPACT MODELS:
RESOURCES FOR DEVELOPERS

Seminars and tutorials for
developing and publishing
compact models



NANOSCIENCE TO SYSTEMS

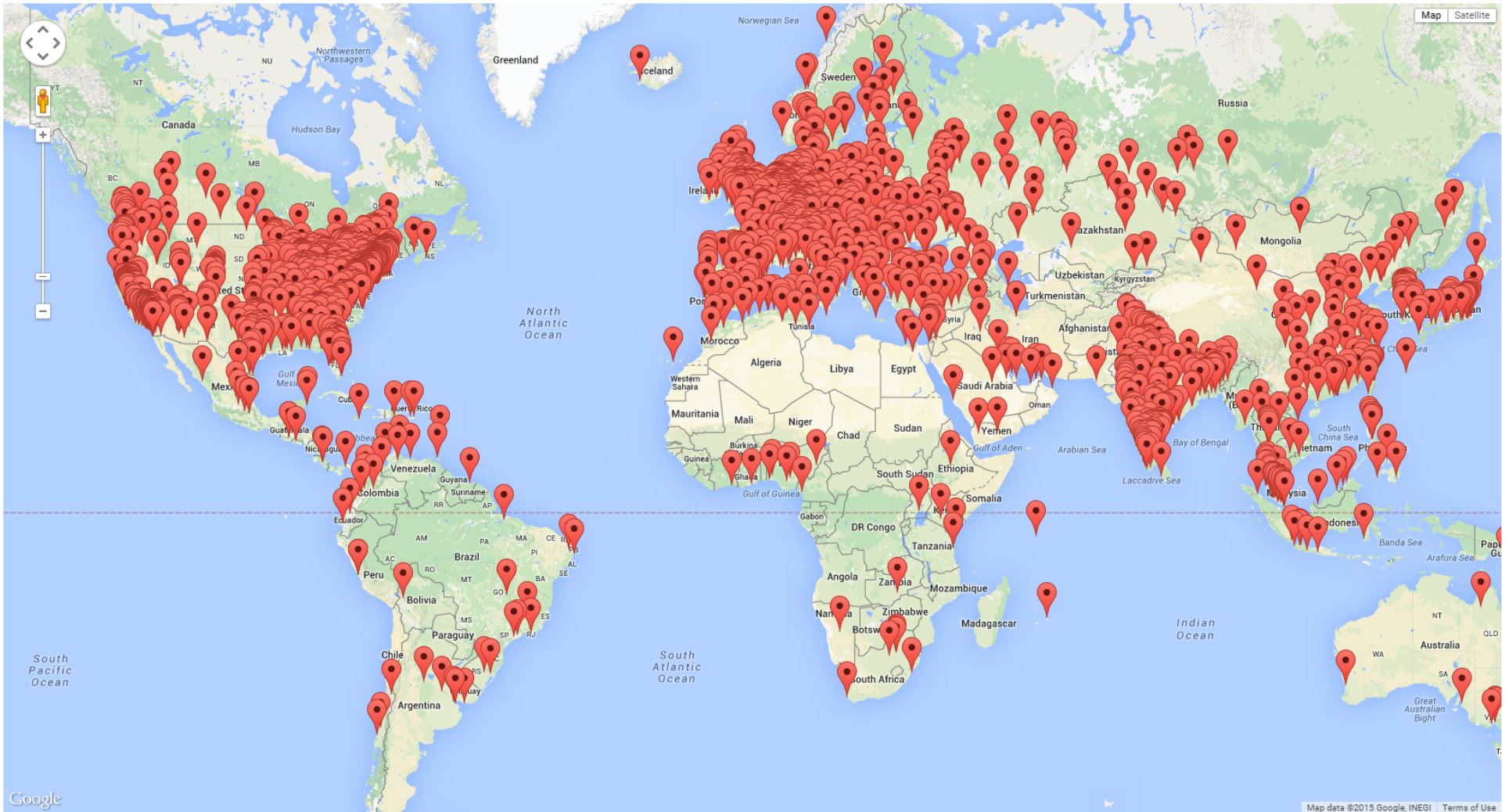
Physically-detailed simulations
system level tools



NANOSCIENCE: SEMINARS,
COURSES, ETC.

NEEDS Seminars, workshops,
nanoHUB-U and more

needs.nanohub.org



NEEDS

Driven by problems and applications



R and D accelerated by tools, cyberinfrastructure, education