Towards Sustainable Computing:
Innovative Design and Management Strategies Across the Computing Stack
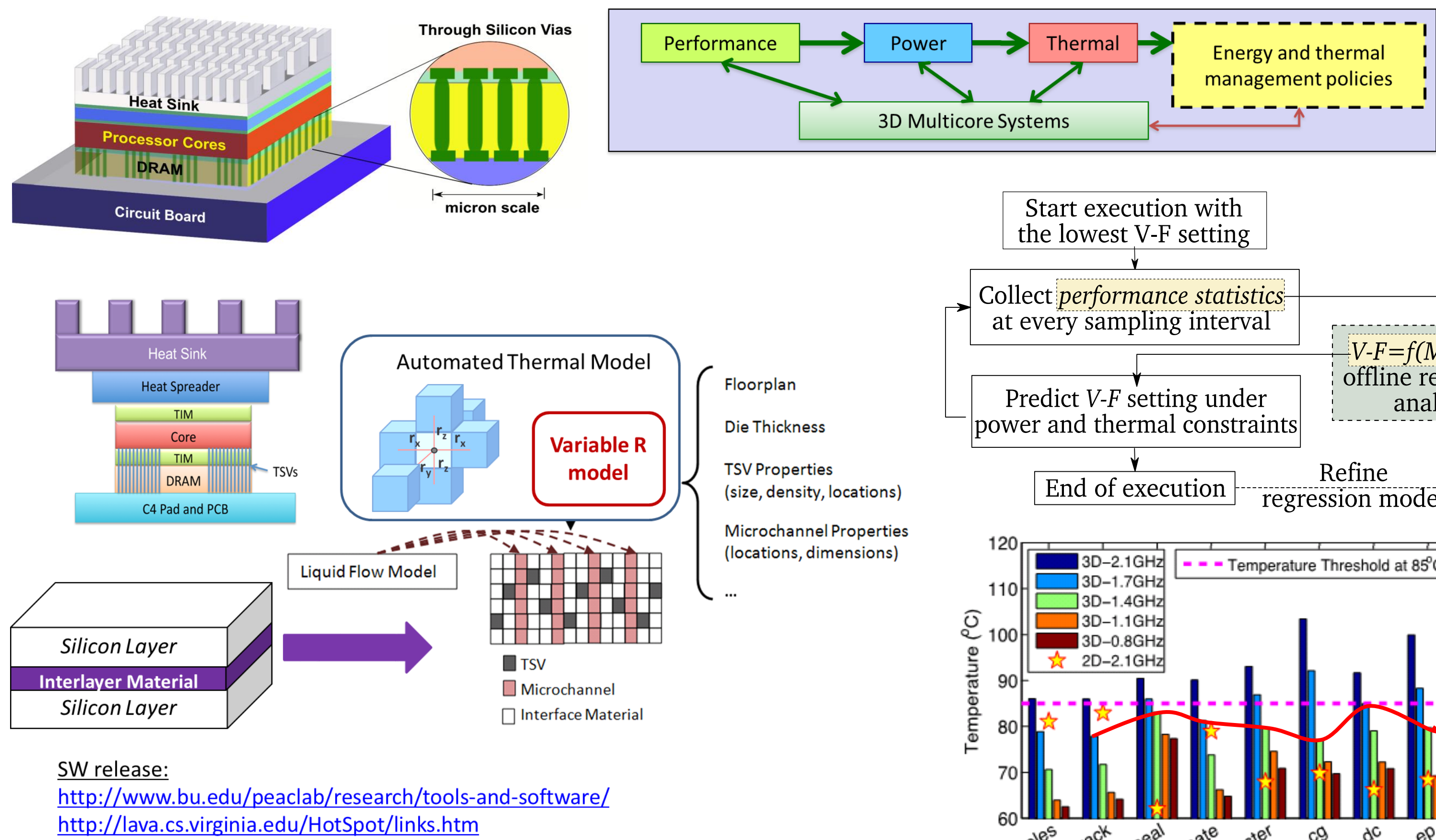
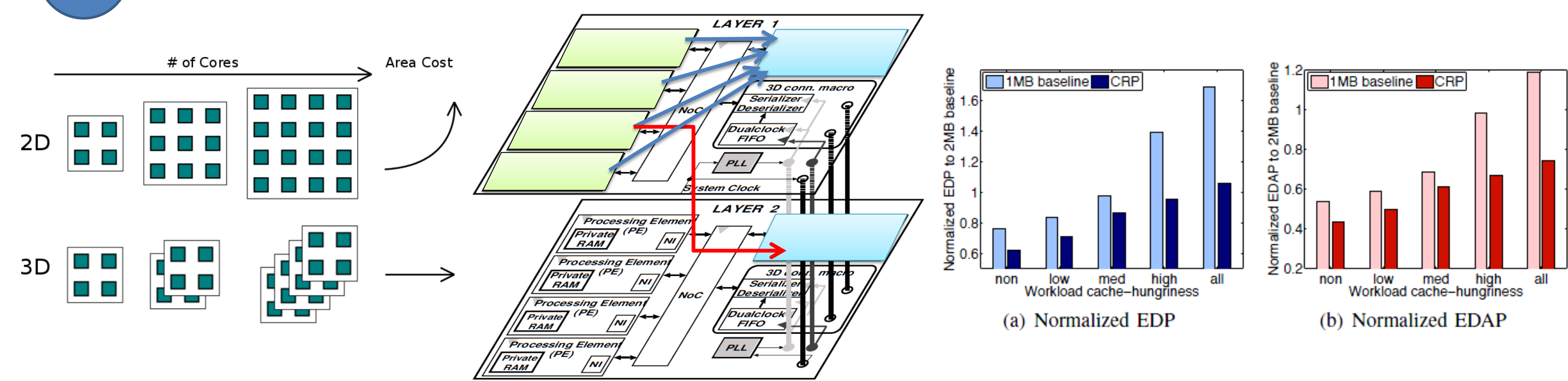*Prof. Ayse K. Coskun*, Electrical and Computer Engineering, Boston University - *acoskun@bu.edu*

PEACLAB
BOSTON UNIVERSITY

Performance and Energy Aware
Computing Laboratory
www.bu.edu/peaclab

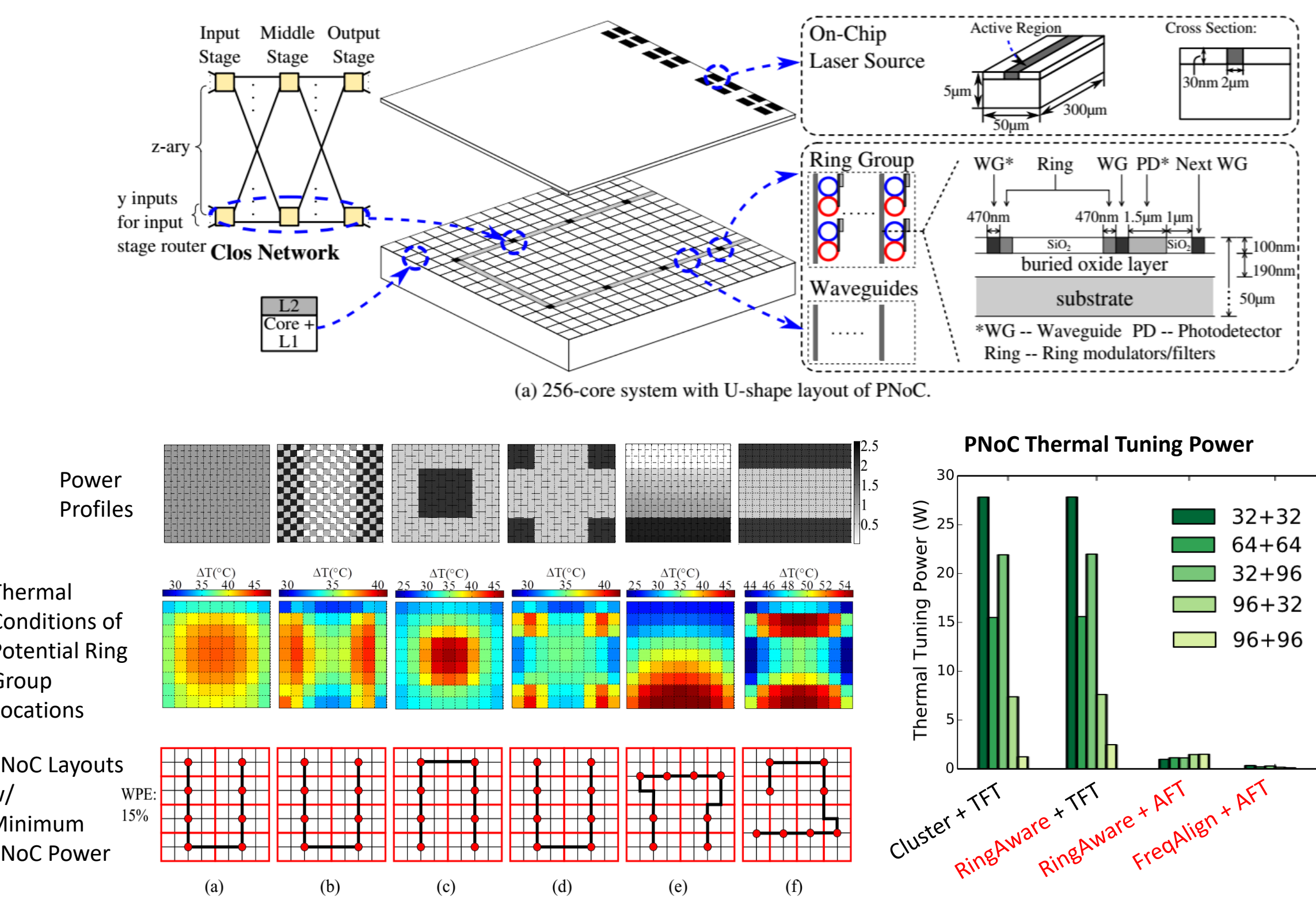
1 New modeling methods and tools for 3D-stacked systems

Through Silicon Vias

Performance → Power → Thermal → Energy and thermal management policies → 3D Multicore Systems

micron scale

Automated Thermal Model

Variable R model

- Floorplan
- Die Thickness
- TSV Properties (size, density, locations)
- Microchannel Properties (locations, dimensions)
- ...

Liquid Flow Model

Silicon Layer
Interlayer Material
Silicon Layer

- TSV
- Microchannel
- Interface Material

Start execution with the lowest V-F setting → Collect *performance statistics* at every sampling interval → Predict V-F setting under power and thermal constraints → End of execution → Refine regression model

$V\text{-}F = f(MA, IPC)$ offline regression analysis

Temperature Threshold at 85°C

SW release:
http://www.bu.edu/peaclab/research/tools-and-software/
http://lava.cs.virginia.edu/HotSpot/links.htm

2 Advancing architecture and system management

(a) Normalized EDP
(b) Normalized EDAP

3D Stacked Systems for Low-Power High-Performance Computing
(NSF CAREER 2012-2017)

3 Heterogeneous integration with new devices and advanced cooling

(a) 256-core system with U-shape layout of PNoC

Power Profiles

Thermal Conditions of Potential Ring Group Locations

PNoC Layouts w/ Minimum PNoC Power

PNoC Thermal Tuning Power
- 32+32
- 64+64
- 32+96
- 96+32
- 96+96

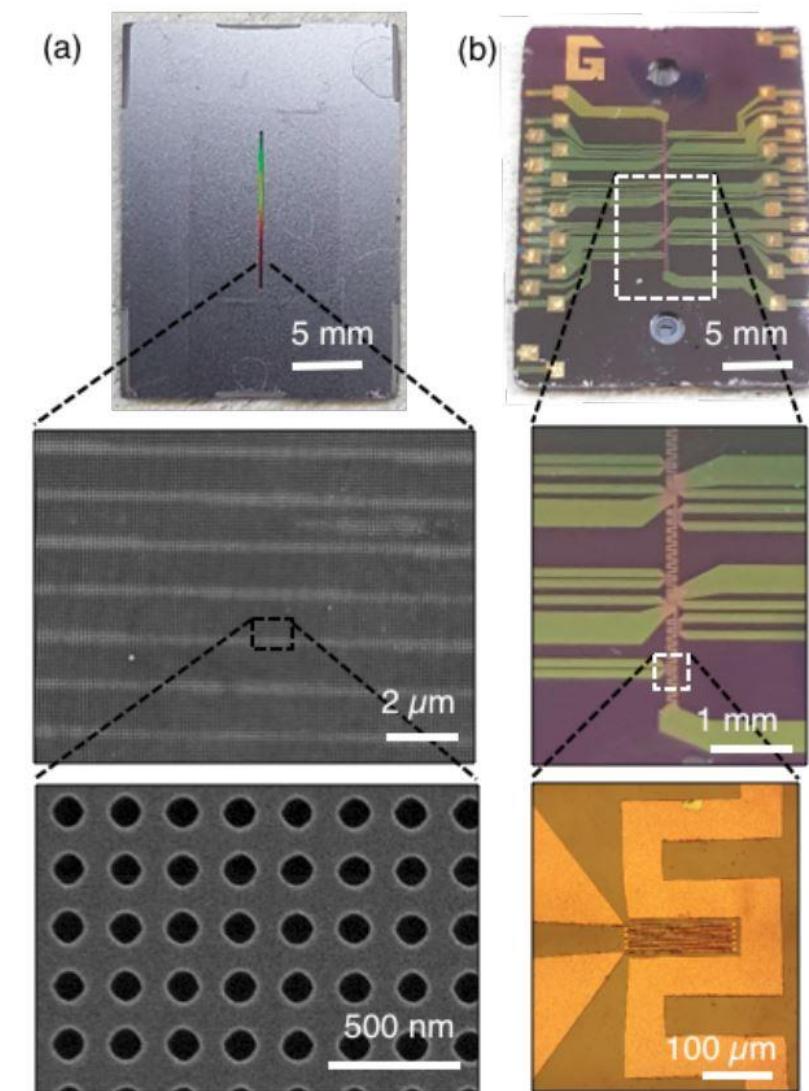Cluster + TFT | RingAware + TFT | RingAware + AFT | FreqAlign + AFT

Outcomes:
- Supported (partially) 3 PhD theses: Dr. J. Meng, Dr. T. Zhang and Dr. F. Kaplan.
- 2 book chapters and a number of journal and conference papers, including IEEE TCAD'17, DATE'16, ACM JETC'15, DATE'14, TCAD'13, DAC'12, and others.
- 3D prototype design: 3D-MMC (DATE'13).
- Software release: 3D detailed thermal modeling tool (integrated into HotSpot v6.0)
- Outreach: undergraduate projects, high school interns, lectures/labs at summer sessions for high school girls, 20+ invited talks at academia and industry

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Modeling the Next-Generation Hybrid Cooling Systems for High-Performance Processors
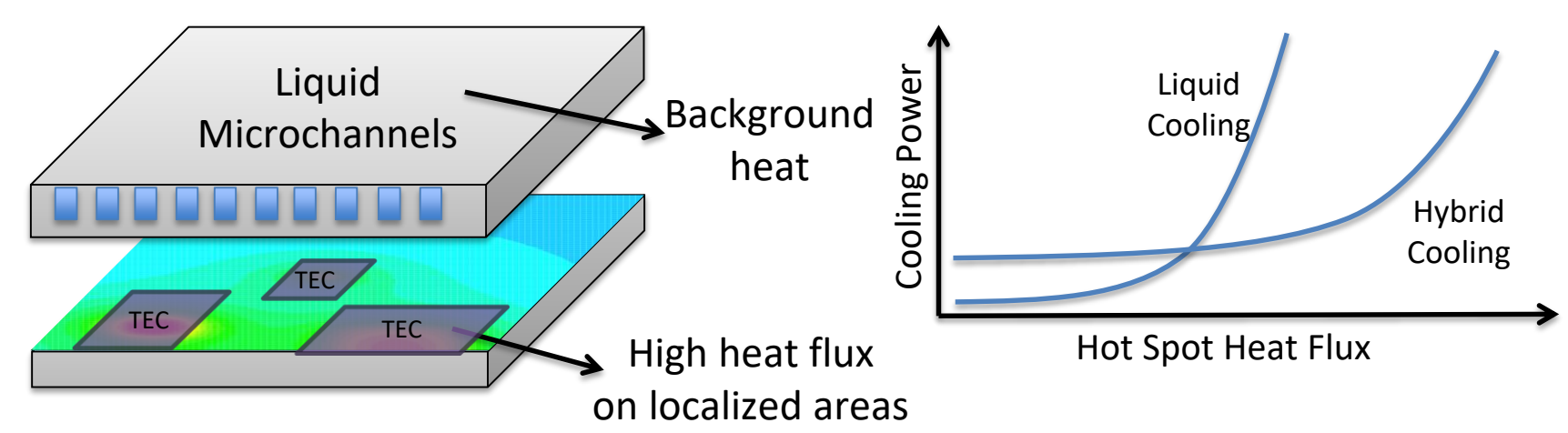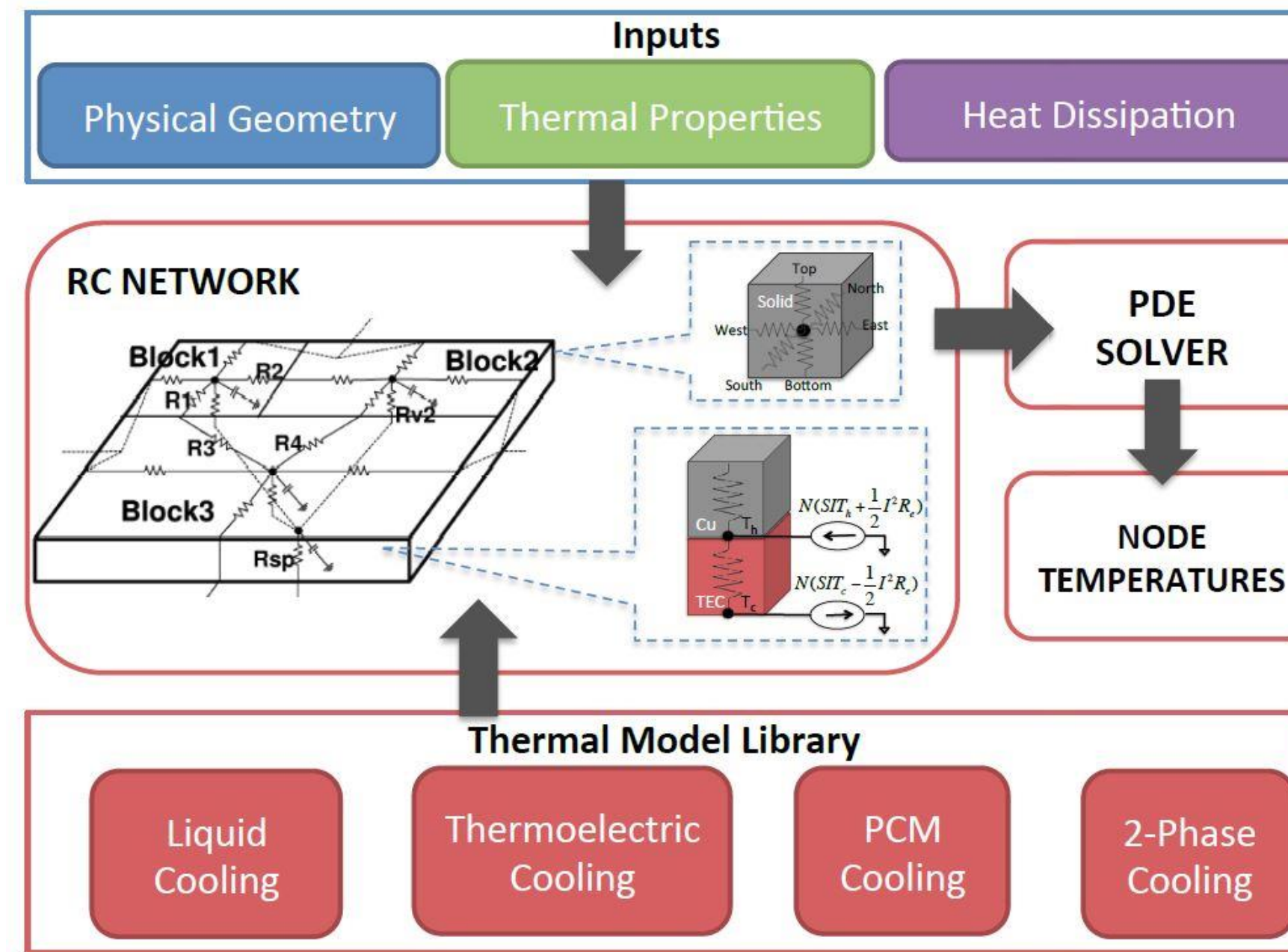### (NSF CRI CI-NEW 2017-2020)
Collaborators: S. Reda @ Brown, E. Wang @ MIT

Nanoporous evaporation test device fabricated at MIT (Courtesy: E. Wang @ MIT).

Inputs
- Physical Geometry
- Thermal Properties
- Heat Dissipation

RC NETWORK
Block1 | Block2 | Block3

PDE SOLVER → NODE TEMPERATURES

Thermal Model Library
- Liquid Cooling
- Thermoelectric Cooling
- PCM Cooling
- 2-Phase Cooling

Hybrid Cooling Co-Design:
- Encapsulate dynamics of *cutting-edge cooling methods* into compact thermal models
- Mix and match the best-fit cooling methods with the computing system
- Localize placement of advanced cooling over hot spots
- Optimize design and runtime decisions (computing and cooling systems)

Liquid Microchannels — Background heat
High heat flux on localized areas

Cooling Power — Hot Spot Heat Flux — Liquid Cooling / Hybrid Cooling

Sample focus research projects enabled:
- Localized cooling co-design for carbon nanotube processors
- Designing a heterogeneous computer with a hybrid cooling system
- Next-generation energy efficient data centers
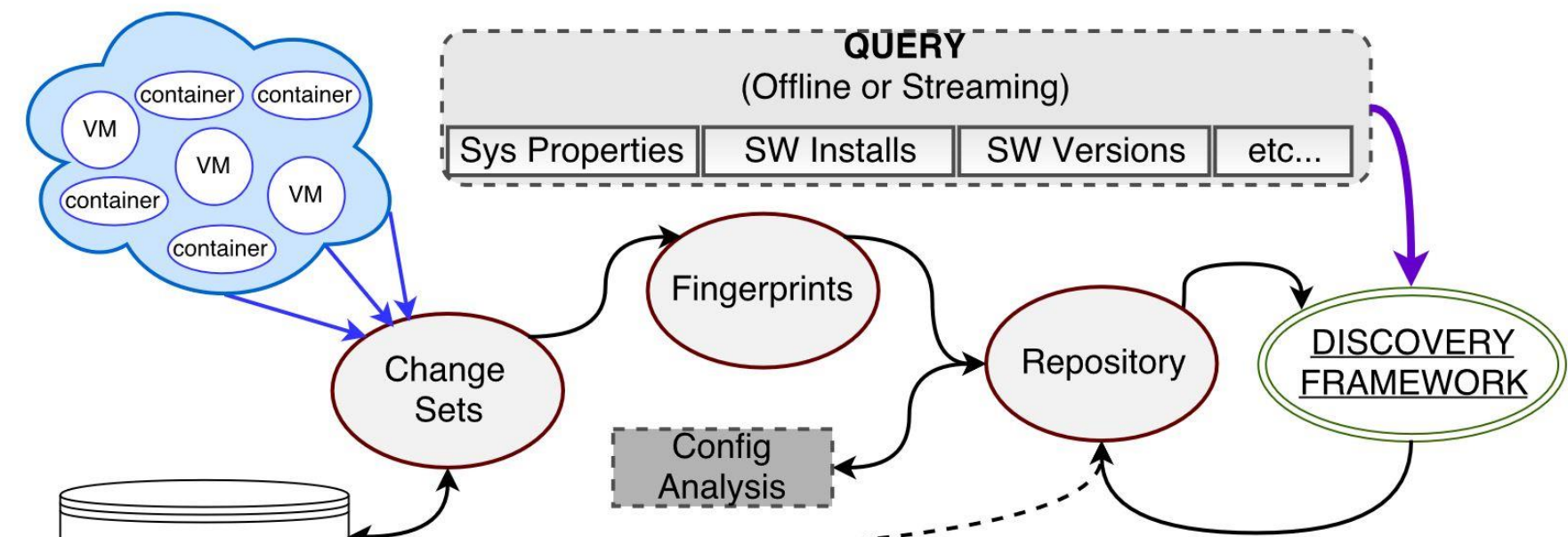- Thermal side-channel proof systems

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Sustainable IT and IT for Sustainability: Data Centers in the Smart Grid
Collaborators: M. Caramanis and Y. Paschalidis @BU; S. Reda @Brown

Multi-level load queues

Data center cooling control

Performance, power & temperature models

Workload arrivals

$P_{cooling}$
$P_{computing}$

Optimal control & allocation of power caps

Load forecasting & bidding in the energy market

Racks — Sensor feedback — Multi-core server

Data Center

Regulation requests

ISOs

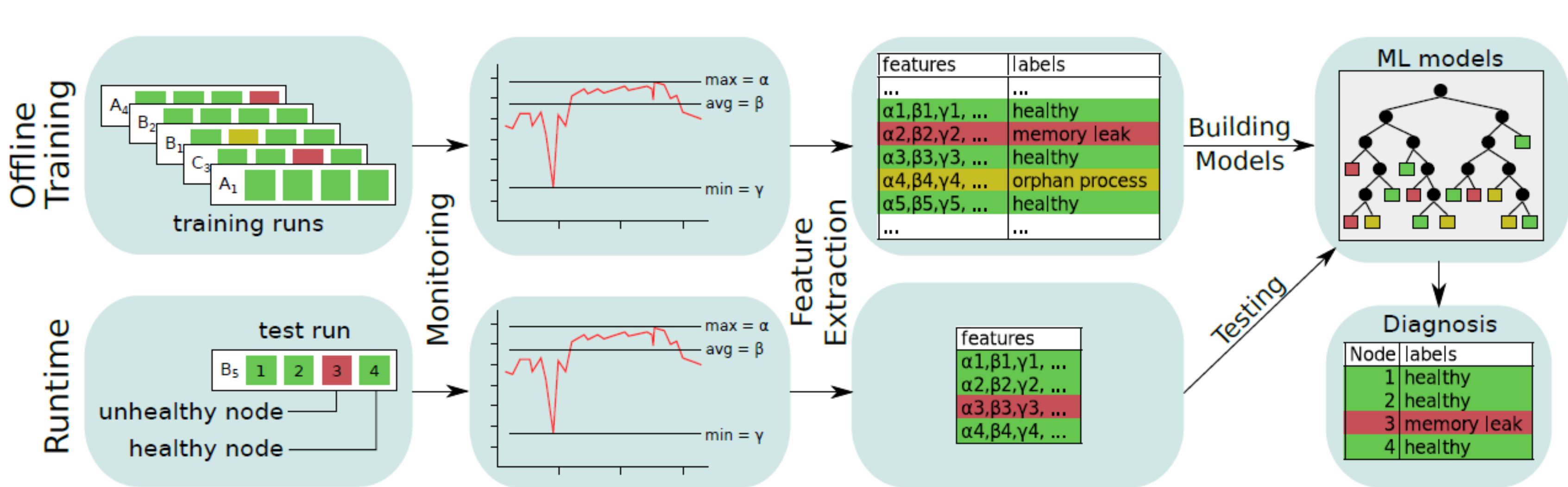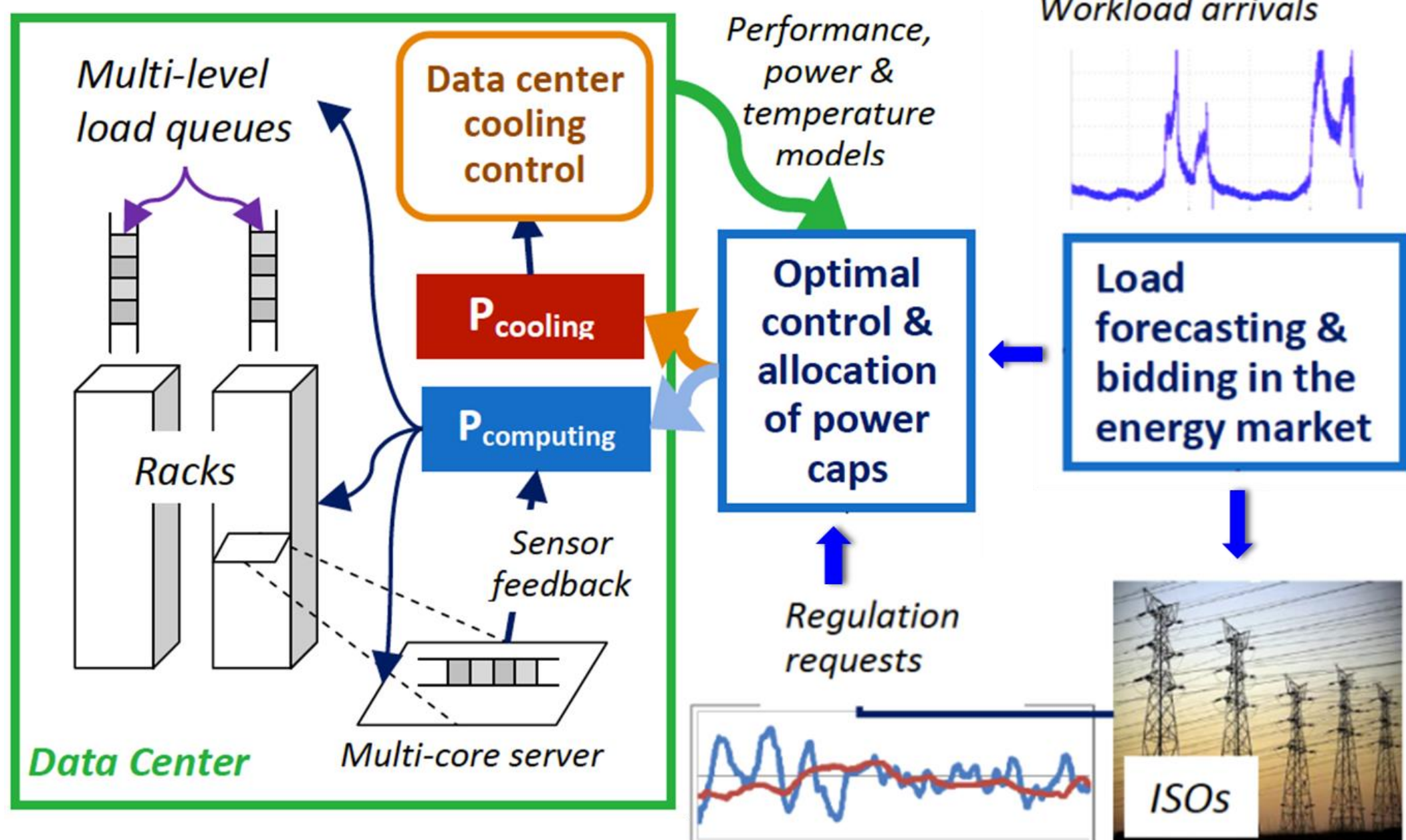[CDC'15, CDC'13, ASPDAC'14, IGCC'14, ICCAD'13]

Automated Analytics for Improving Efficiency, Safety, and Security of HPC Systems
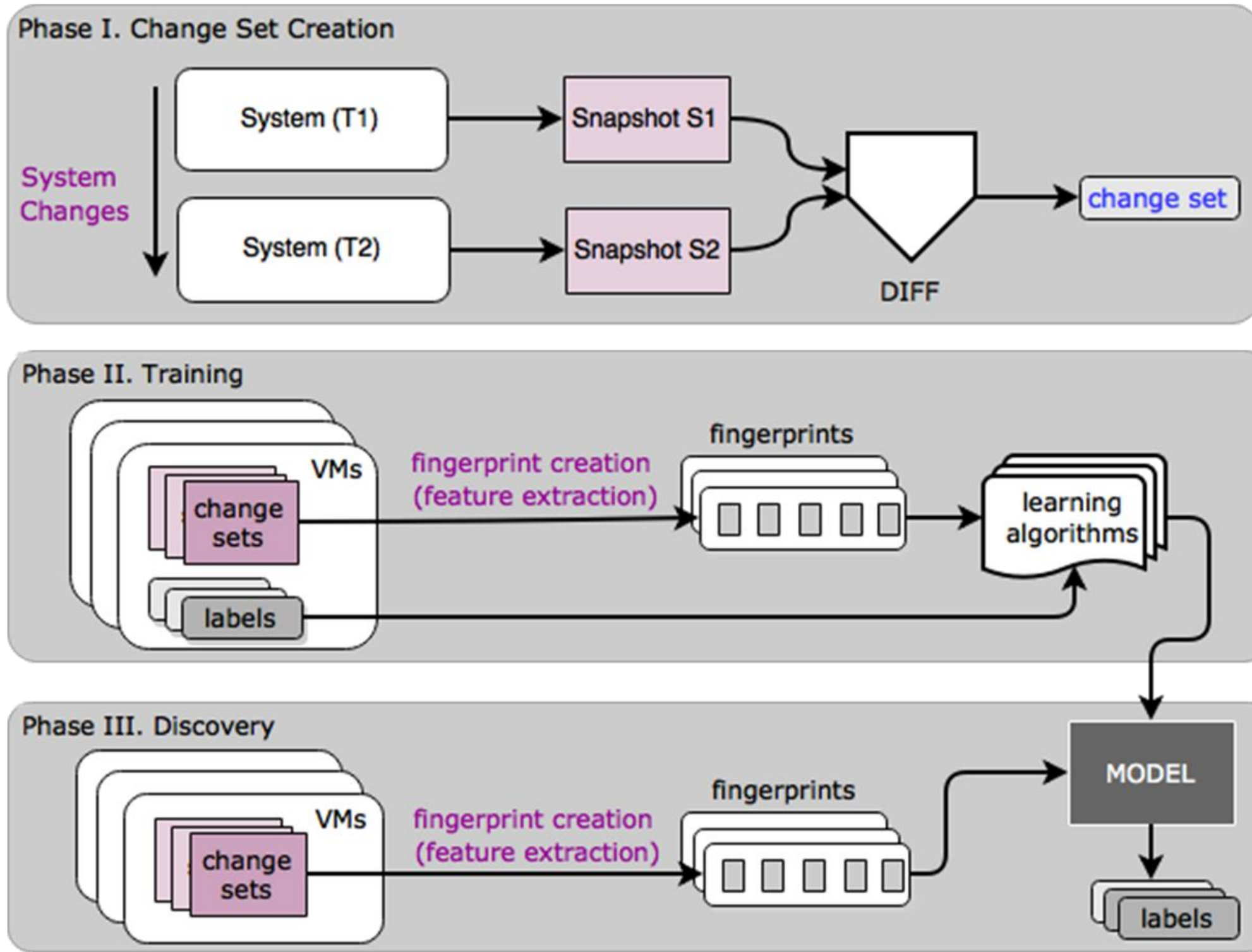### Collaborators: M. Egele and A. Turk @ BU; V. Leung and J. Brandt @ Sandia Labs

Offline Training — training runs — Monitoring

max = α
avg = β
min = γ

Feature Extraction

features	labels
α1,β1,γ1, ...	healthy
α2,β2,γ2, ...	memory leak
α3,β3,γ3, ...	orphan process
α4,β4,γ4, ...	healthy
α5,β5,γ5, ...	healthy

Building Models → ML models

Runtime — test run — unhealthy node / healthy node

Testing → Diagnosis

Node	labels
1	healthy
2	healthy
3	memory leak
4	healthy

[ISC-HPC'17 – Gauss Award]
[Usenix CoolDC'16]

Scalable Software and System Discovery in the Cloud
Collaborators: A. Turk @ BU; C. Isci, S. Duri, N. Bila @ IBM TJ Watson

QUERY (Offline or Streaming)
Sys Properties | SW Installs | SW Versions | etc...

Change Sets → Fingerprints → Repository → DISCOVERY FRAMEWORK
Config Analysis
Knowledge Base

Phase I. Change Set Creation
System (T1) → Snapshot S1
System (T2) → Snapshot S2
DIFF → change set

Phase II. Training
change sets → fingerprint creation (feature extraction) → fingerprints → learning algorithms
labels

Phase III. Discovery
change sets → fingerprint creation (feature extraction) → fingerprints → MODEL → labels

[IEEE Big Data'16]
[IBM Journal'16]
[IEEE Big Data'14]