System Simulation & Performance Prediction for 51,000,000 Endpoints

Arun Rodrigues
Sandia National Labs

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

View of the problem

Scale.....

Many Cores + Memory **X** Many Many Nodes **X** Many Many Many Threads

Multiple Audiences.....

Network Processor System **X** Application writers purchasers designers **X** system procurement algorithm co-design architecture research language research **X** present systems future systems

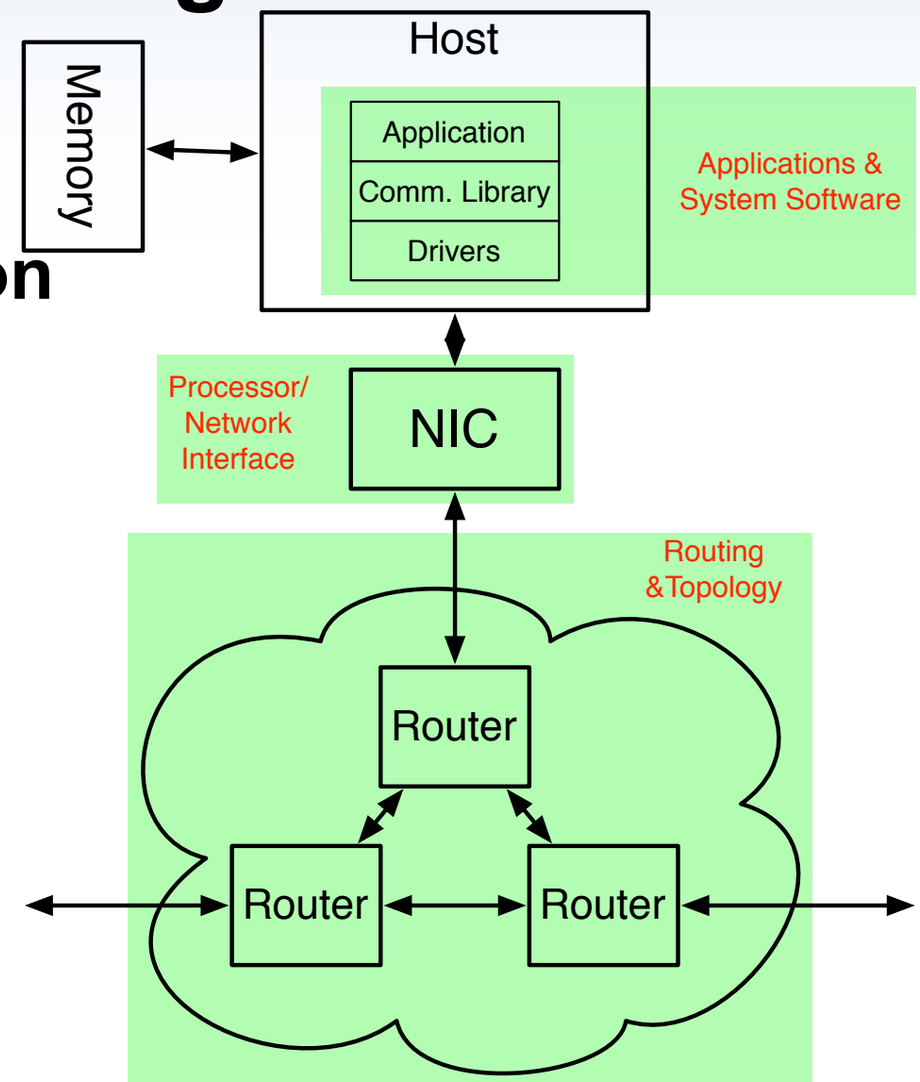
Complexity.....

Multi-Physics Apps Informatics Apps **X** Communication Libraries Run-Times OS Effects **X** Existing Languages New Languages

Constraints.....

Performance Cost | Power Reliability | Cooling Usability | Risk Size

HPC Simulation Challenges



- Multiple User communities
  - Procurement: Architecture Evaluation
    - Is this the right machine to buy?
  - Application Writers: Optimization
    - How will code run on this machine?
  - Architects: Design
    - What should the machine look like?
- What level of detail?
- What subsystems examined?

- Current Simulators...
  - Cycle-accurate node-level (accurate, slow)
  - Stochastic network models (accurate?, lose details)
  - FPGA (detailed, fast, hard to develop/scale)

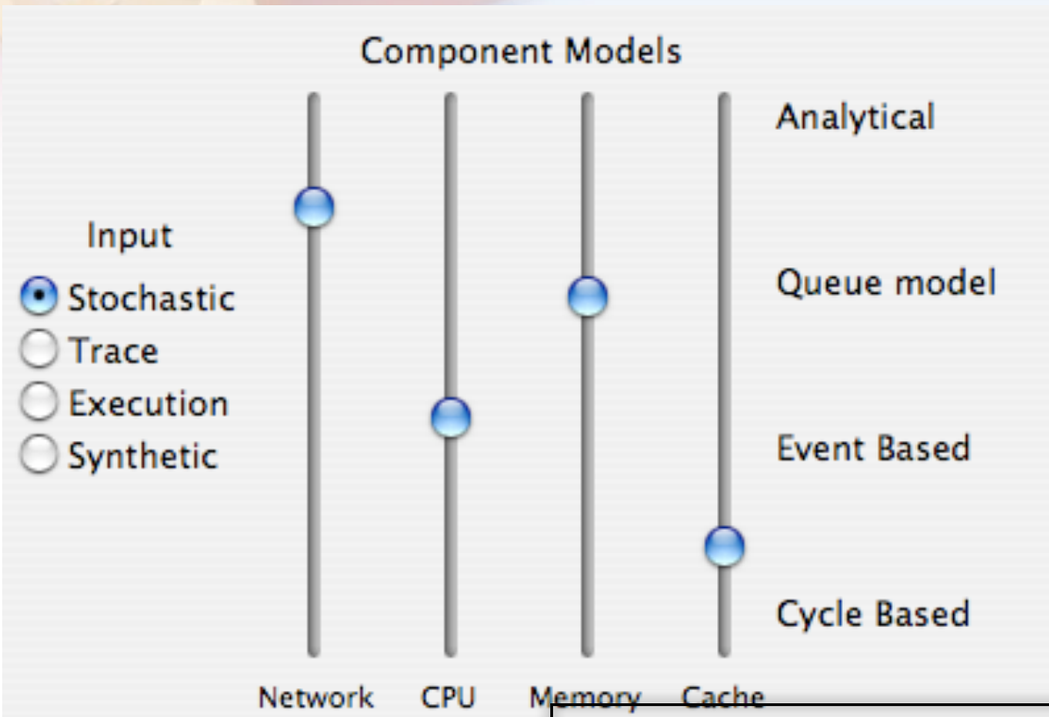
HPC Simulation: Main Challenges

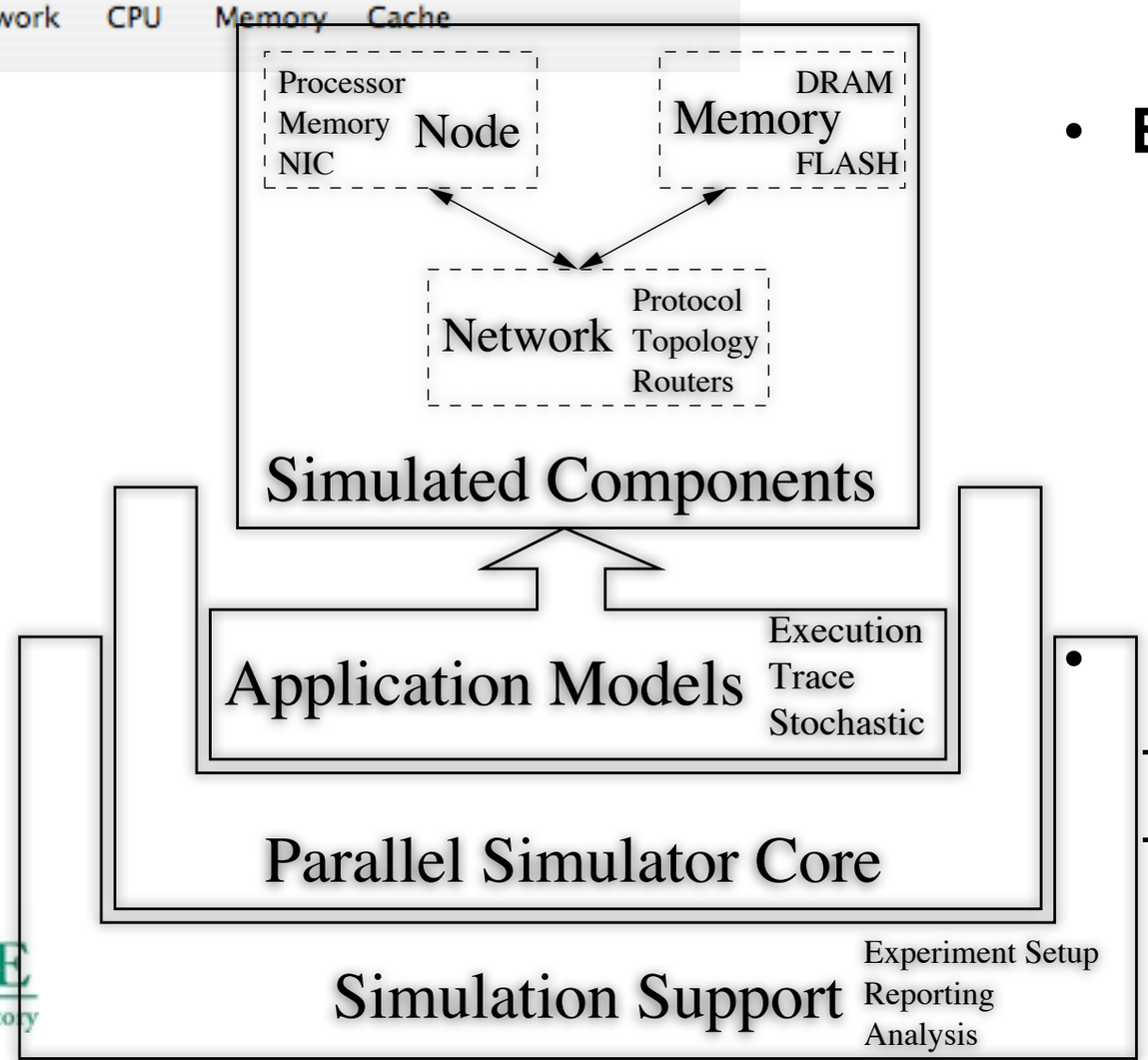
- **Network/Application Feedback**: A static trace or simple statistical model will not capture the causal relationships between messages.
- **Scalability**: Many network effects only become apparent at hundreds or thousands of nodes.
- **Variable Processor/Memory/Network Systems**: Local interactions can have global performance implications.
- **Ability to Model Message Overheads:** Overheads in the network (e.g. packetization, protocol overhead) and messaging library (e.g. MPI matching, message assembly) can have a major effect on performance.
- **Ability to Explore Programming Models**: Novel hardware will require novel programming techniques and capabilities.
- **Power and Economic Effects:** Power and cost are the key limiting factors on system design. Any system model must be able provide feedback on the power and cost implications of new architectural features.

Promising Technologies

- Supercomputers to design Supercomputers
- Critical mass of component simulators
  - Processors
  - Memory
  - Network
  - ...in isolation
- Critical mass of application models
  - Compact Apps
  - Scalable application models
  - State machine models
  - Message traces
- New simulation super-projects...

IAA Simulator

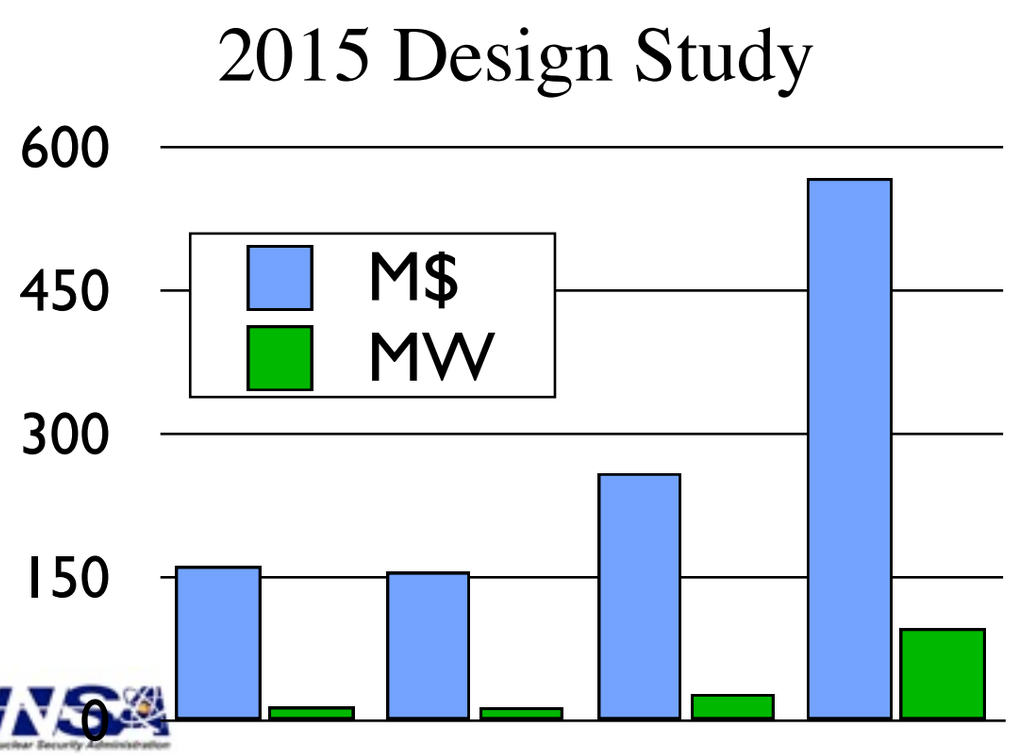


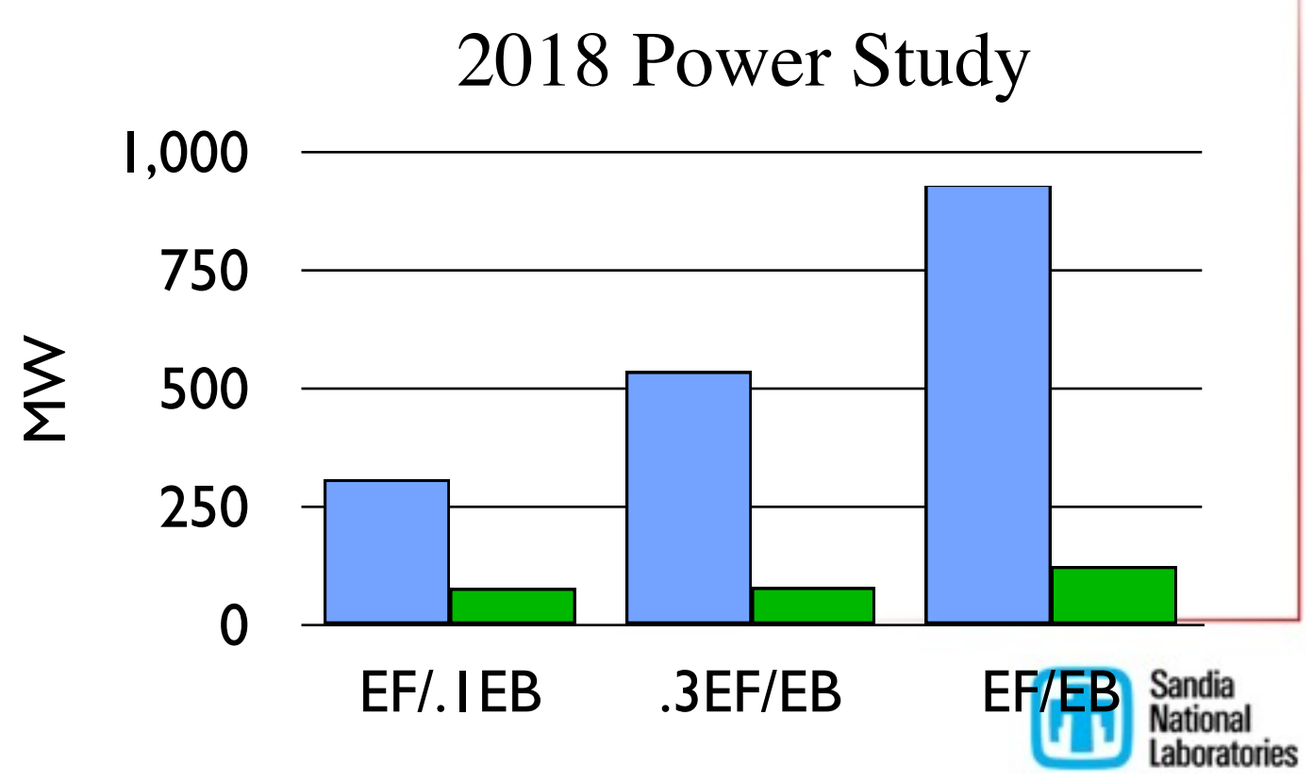


- **Key features**
  - **Highly scalable parallel simulator**
  - **Multi-scale simulation**
    - **Instruction-level**
    - **Message-level**
    - **FPGA**
  - **Technology model interface**
  - **HPC Focus**
- **Elements**
  - **Multi-scale component library**
  - **Multi-scale application models**
  - **Parallel simulation core**
  - **Simulation support**
- **Open issues...**
  - **Validation**
  - **Multi-scale**

Will complexity doom us to build what we can model/predict?

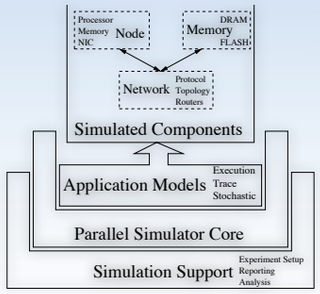
- No!
- Inability to predict has never stopped us before!
- Should it?
- Yes!
  - Systems more complex, larger
  - Will require major investments ($10s Millions in power alone!)
  - New programming models, packaging, architectures need evaluation



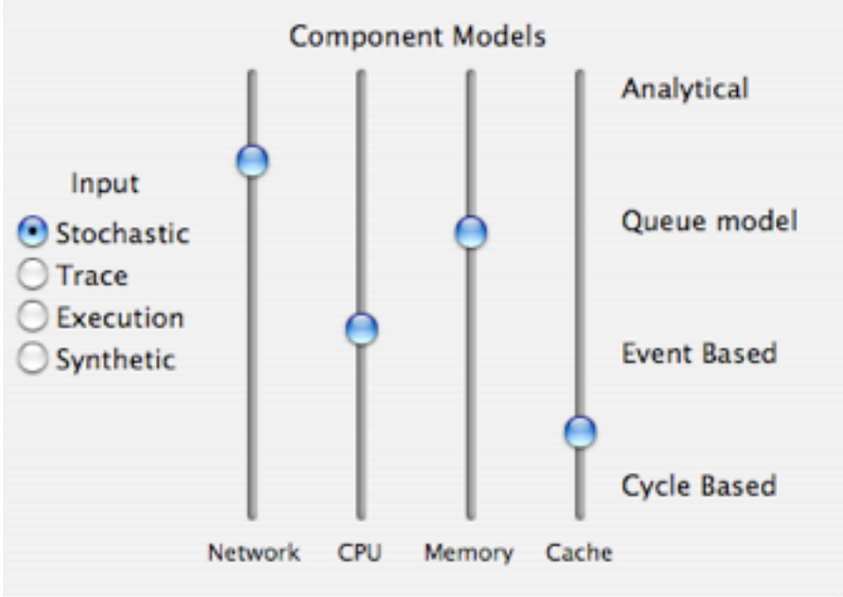


Bonus Slides

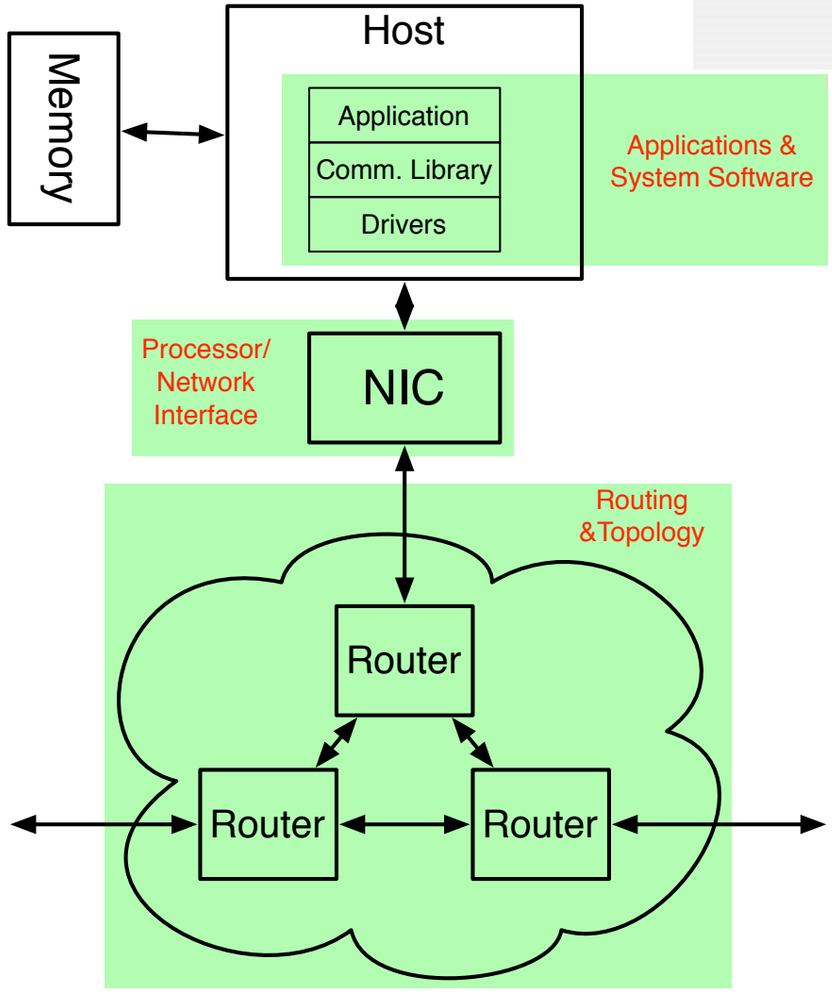
Simulated Components



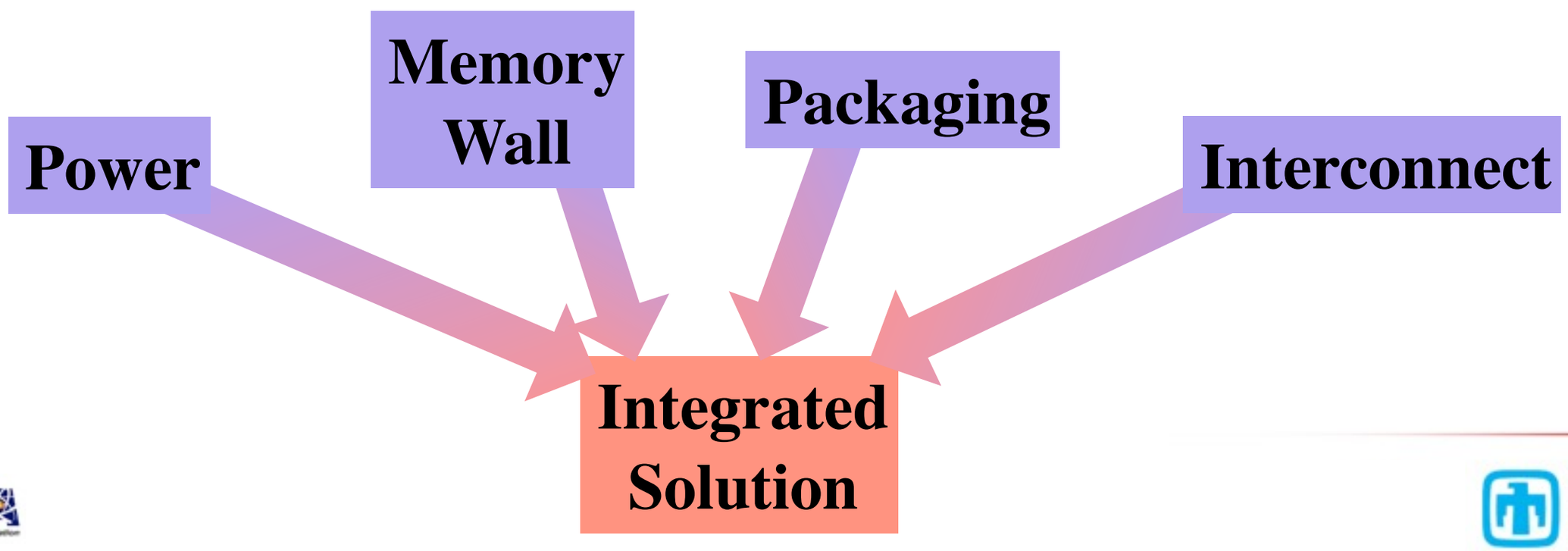
- Usual suspects...
  - Processors
  - Memory systems
    - Build on DRAMSim models
  - Interconnect: NICs, Routers
    - Build on Red Storm models
    - Topology models
- Multiscale
  - Cycle-accurate
  - Cycle-approximate
  - Statistical
  - FPGA
- Hooks
  - Power
  - Area
  - Visualization



Multiscale Parameters



Economic

Existing industry trends not going to meet HPC application needs

- **Semi-conductor industry trends**
  - **Moore's Law still holds, but clock speed now constrained by power and cooling limits**
  - **Processors are shifting to multi/many core with attendant parallelism**
  - **Compute nodes with added hardware accelerators are introducing additional complexity of heterogeneous architectures**
  - **Processor cost is increasingly driven by pins and packaging, which means the memory wall is growing in proportion to the number of cores on a processor socket**
- **Development of large-scale Leadership-class supercomputers from commodity computer components requires collaboration**
  - **Supercomputer architectures must be designed with an understanding of the applications they are intended to run**
  - **Harder to integrate commodity components into a large scale massively parallel supercomputer architecture that performs well on full scale real applications**
  - **Leadership-class supercomputers cannot be built from only commodity components**