70 YEARS OF CREATING TOMORROW

Los Alamos NATIONAL LABORATORY

Adjusting to Exascale Computing

Do Domain-Specific Languages Stand a Chance?

Patrick McCormick

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NNSA National Nuclear Security Administration

Overview

- Requirements
- Perspectives: Perceptions & Expectations
- Challenges
- Examples
- Conclusion

ExaCT CENTER FOR EXASCALE SIMULATION OF COMBUSTION IN TURBULENCE

Work supported by: DOE Advanced Scientific Computing Research
Program Managers: Karen Pao, Lucy Nowell

Architecture Design Factors are Impacting Programming Models

The Old Model

- ***Costs***: *FLOPS*
- ***Parallelism***: *By adding nodes*
- ***Memory***: *maintain byte per flop capacity and bandwidth*
- ***Locality***: *Uniform costs within node & between nodes*
- ***Uniformity***

The New Model

- ***Costs***: *data movement*
- ***Parallelism***: *exponential growth within chips*
- ***Memory***: *Compute growing 2x faster than capacity or bandwidth*
- ***Locality***: *Must reason about data locality in increasingly complex memory hierarchies…*
- ***Heterogeneity***

Source: J. Shalf (2013)

The Exascale Paradox: Programming Model Requirements

- minimal impact on existing codes
- maintainability
- interoperability
- productivity
- performance portability

"I want you to find a bold and innovative way to do everything exactly the same way it's been done for 25 years."

The Exascale Paradox: Programming Model Realities

- Data movement
  - Must move away from bulk-synchronous
  - Prefer finding "data independence"
- Parallelism + Concurrency
  - Memory scaling, utilize core counts
  - Asynchronous data movement -- overlap compute and communication
- "Manual" task scheduling, asynchronous data movement, locality decisions will be difficult at best
  - Too complex, potential portability issues

The Exascale Paradox: Programming Model Requirements

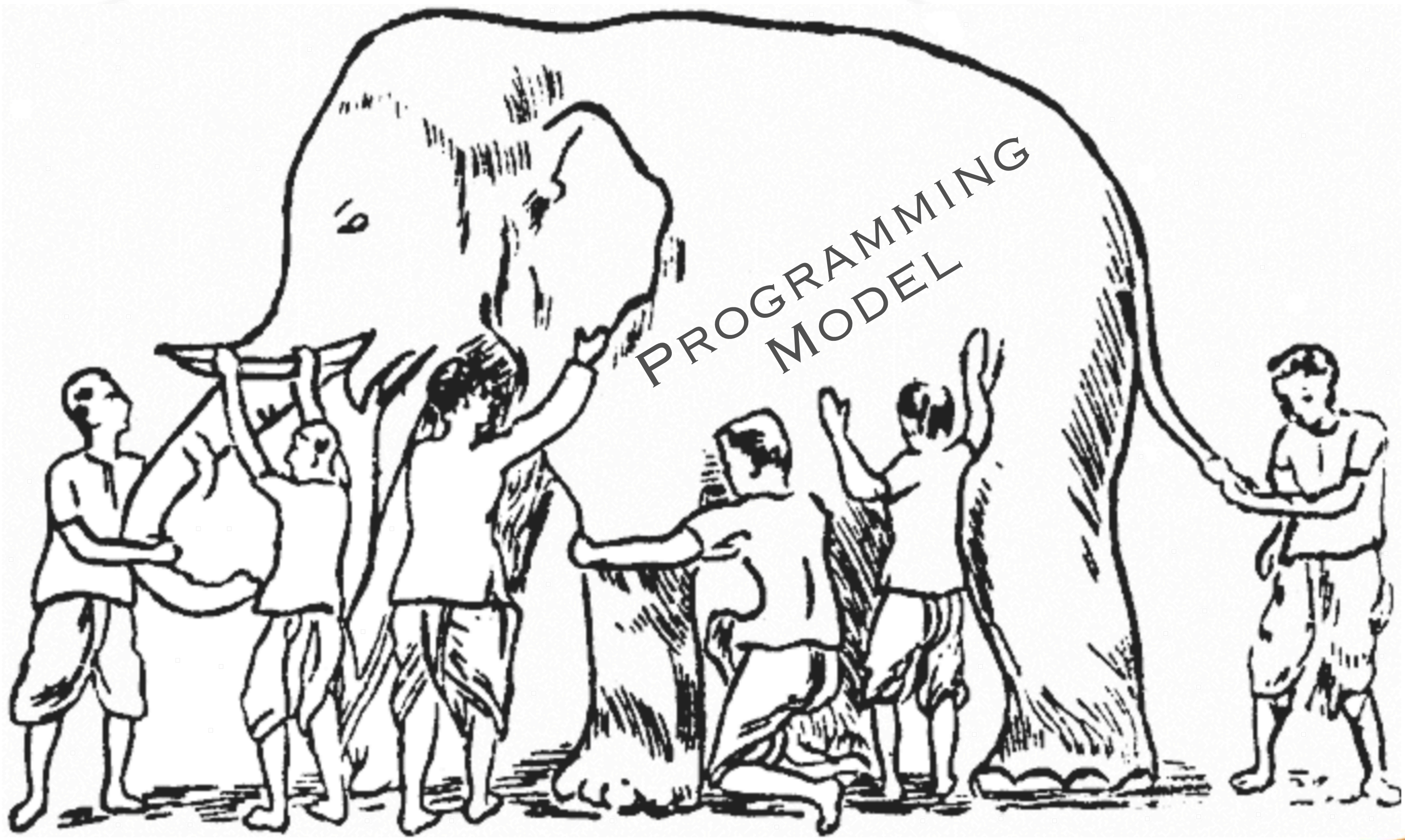
- ~~minimal impact on existing codes~~
- maintainability
- interoperability
- productivity
- performance portability

Thanks – this matches DSLs!!!

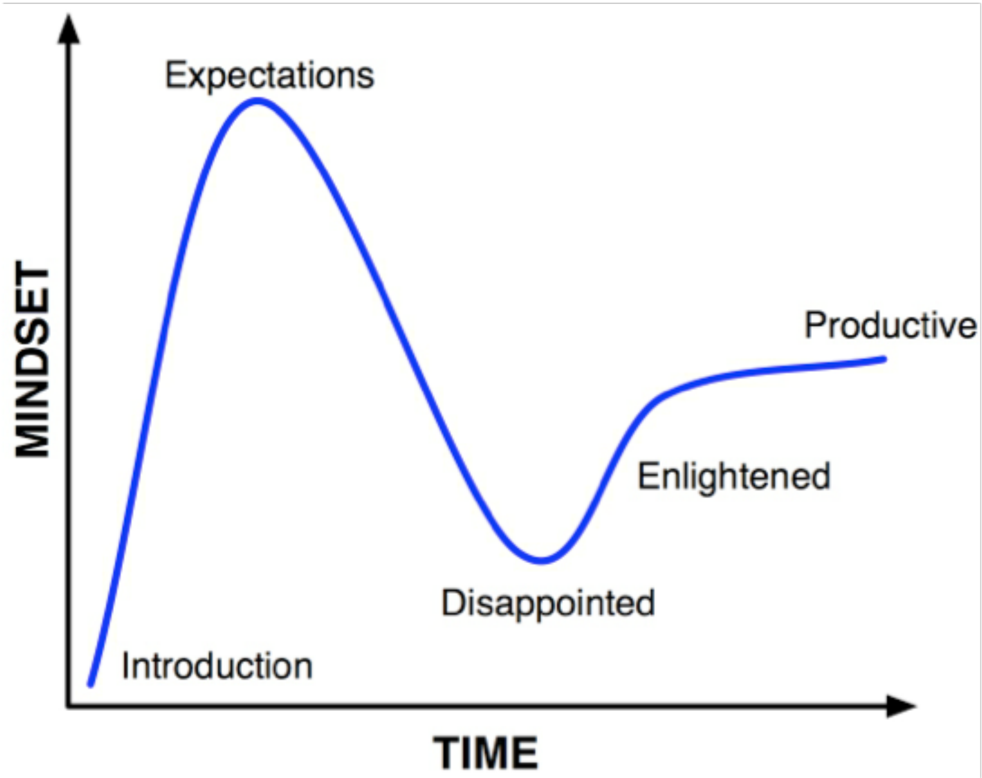
Where are DSLs Best Suited?

- Where complexity abounds and additional knowledge can be significantly leveraged to ease the burden, increase performance
- Small, limited domain within an application
  – Minimal code impact, reduced complexity and maintenance
- More significant / majority of code base
  – Most benefit at the cost of complexity and cost
  – High risk, high reward

What are we facing? What are the perceptions and expectations?



The Hype Curve…



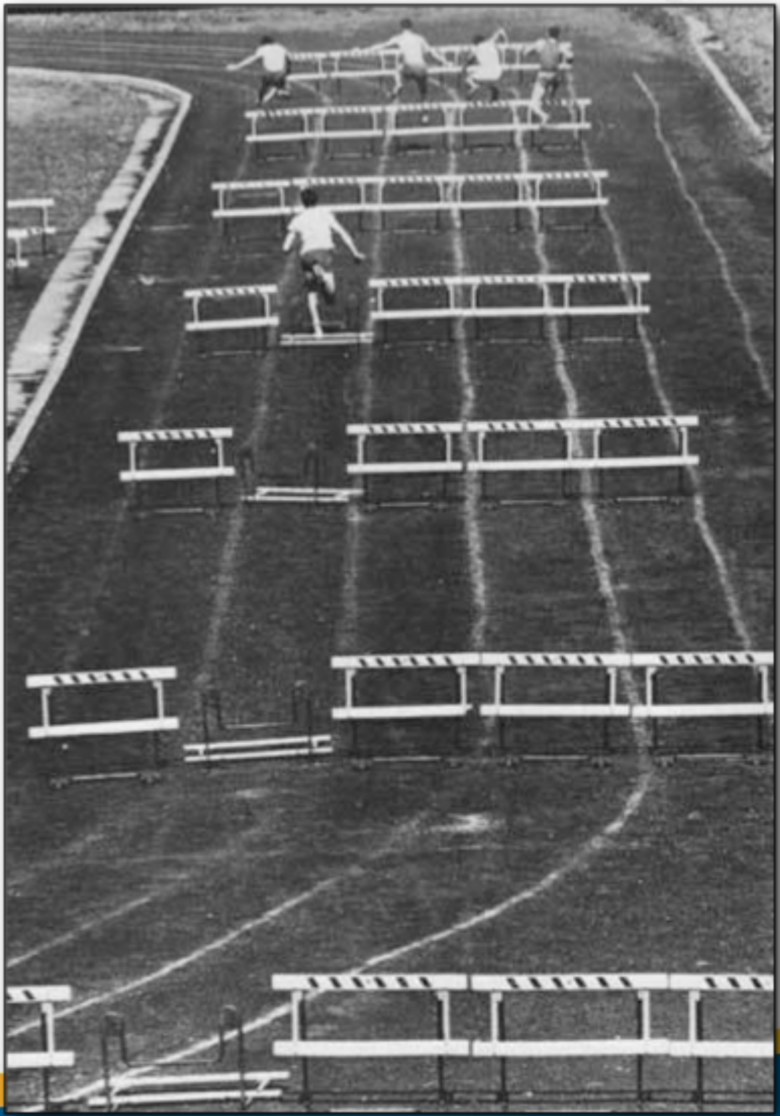
"Mastering the Hype Cycle: How to Choose the Right Innovation at the Right Time" by J. Fenn and M. Raskino

- **Given the history in HPC, it is often impossible to get expectations "high"**
- **It is very easy follow the slope well past "disappointed"**
- **Reaching "enlightened" and maintaining "productive" are difficult ($$$)**

Adoption and Achieving Productivity

- Long-term success needs much more attention and innovation
- Domain-nature must flow through the ***entire*** toolchain
  - Source-to-source is good for prototyping and “small” problems but loss of information/abstraction is painful
  - This means debuggers, profilers, etc.
- Much more complex than just a “new” language
  - Supporting runtime infrastructure(s) are significant for full-system/featured solutions
  - We need better tools to build DSLs

The Adoption (or Rejection) by Embarrassment Principle



Interoperability

- With ***existing code*** *base*
  - We can’t afford to rewrite legacy code and libraries

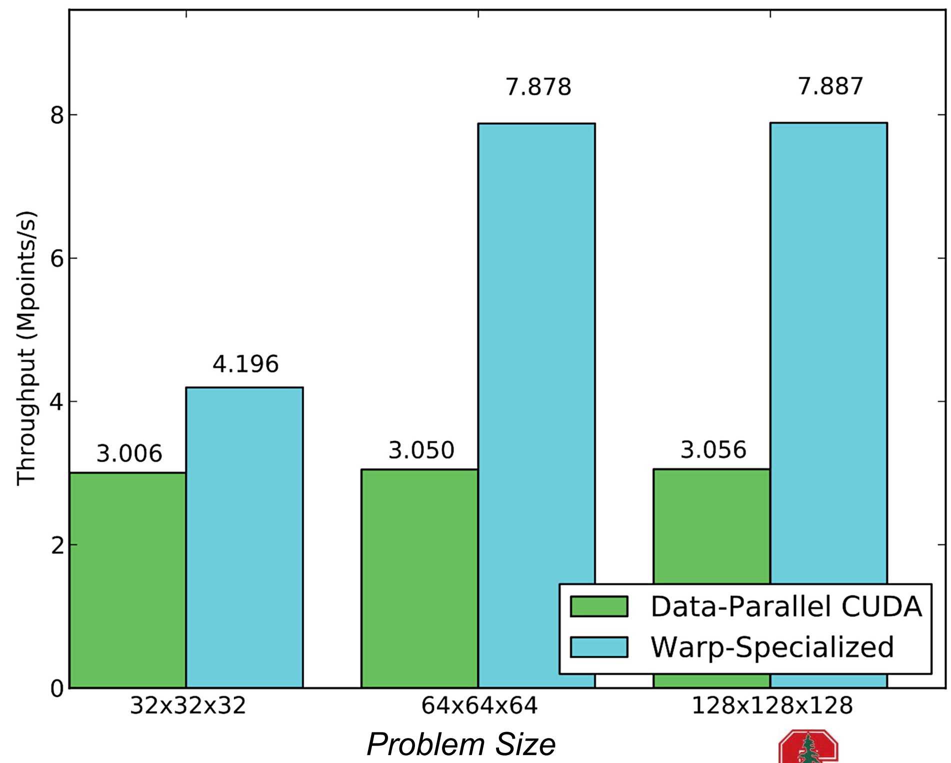
- With other DSLs
  - Complex (e.g. multi-physics) applications might have (need/benefit from) multiple abstractions/models

What to do about Legacy Codes?

- Grin and bear it… Regardless of the path taken, things will need to change…
- We need a ***progressive*** migration path
  - Allow gradual adoption and transformation (likely with an impact on performance)
- Long-term support
  - This often rests in the hands of the application…

Singe: A DSL Compiler for Combustion Chemistry

- *Based on chemical mechanisms* which consist of a set of *reactions* and the *species* involved (CHEMKIN Standard)
- *Challenges*: *Traditional data-parallel approach in CUDA suffers from spilling, low occupancy, under-utilization of math units, large number of temporaries, memory divergence and shared memory bank conflicts.*
- *Warp specialization code-generation not directly supported by CUDA – inline PTX code had be to generated*



Mike Bauer, Stanford University

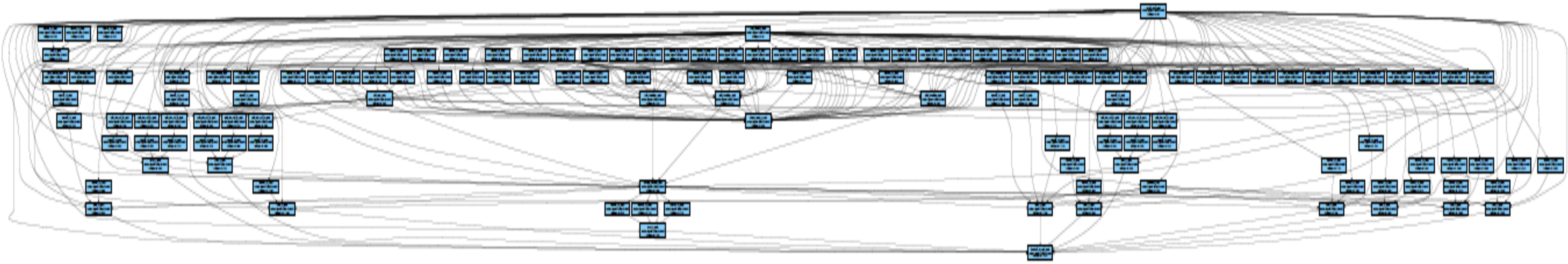
Supporting Runtime Infrastructure

- Specify an abstract data representation, the code that operates on them, and their privileges (read-only, read-write, and reduce) and coherence (e.g., exclusive access and atomic)
- Separately implement how the data and tasks are placed and migrated within the system
  – "Mapping" can be done in an application and/or architecture centric fashion

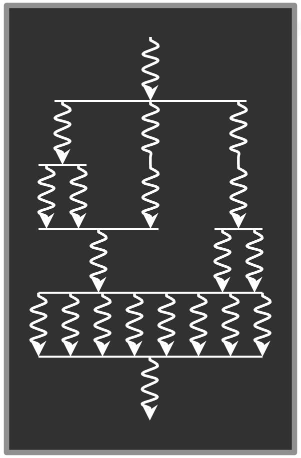
Legion: Expressing Locality and Independence with Logical Regions. M. Bauer, S. Treichler, E. Slaughter and A. Aiken. In Proceedings of the Conference on Supercomputing, pages 66:1-11, November 2012.

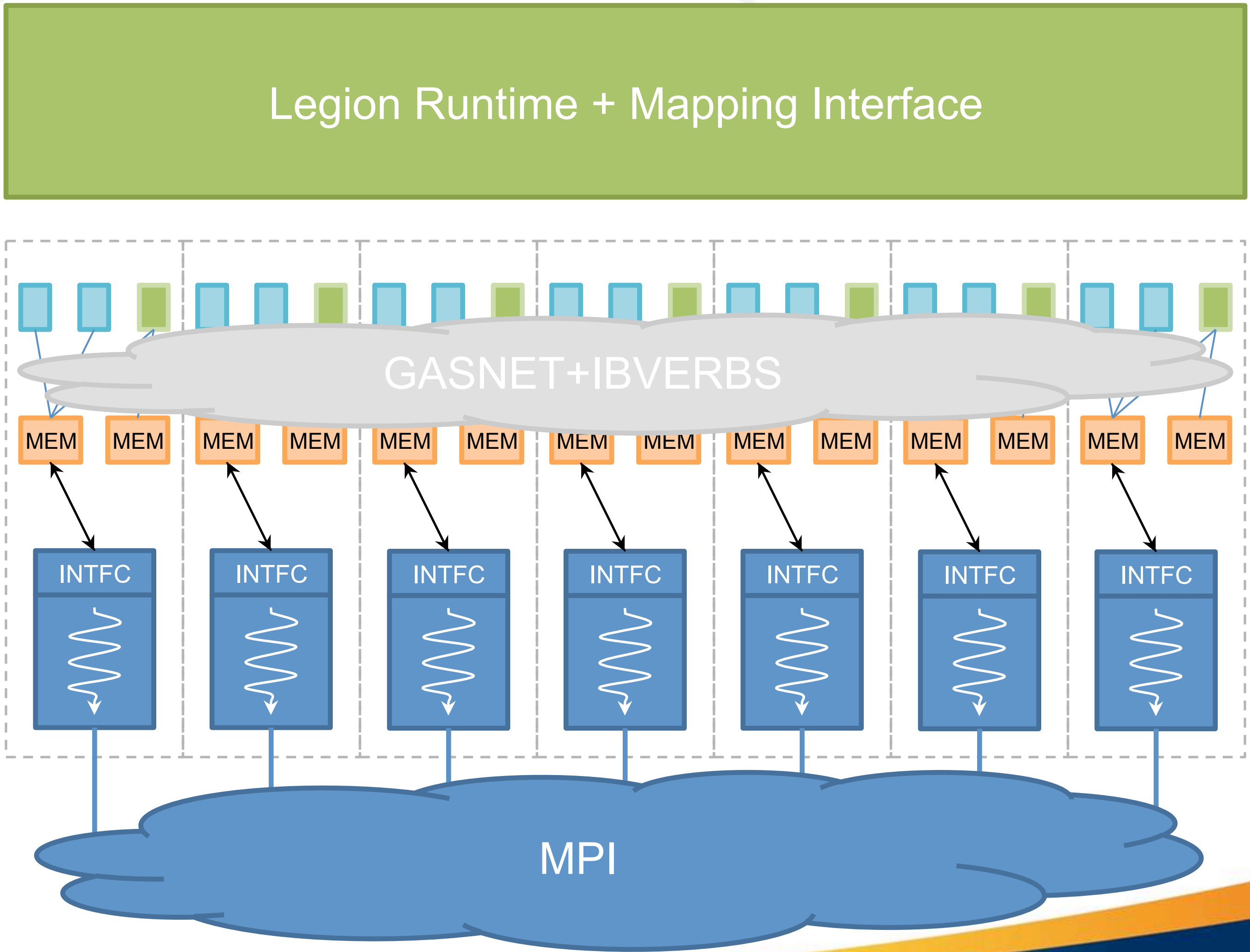
Transforming S3D from Bulk-Synchronous to Data-Independence

- Total tasks/kernels: 781 (44,517 system-wide)
  - Max task tree depth: 4
  - Max task-level parallelism: 57 (widest the task dependence graph gets)
  - Total data fields: 1,140



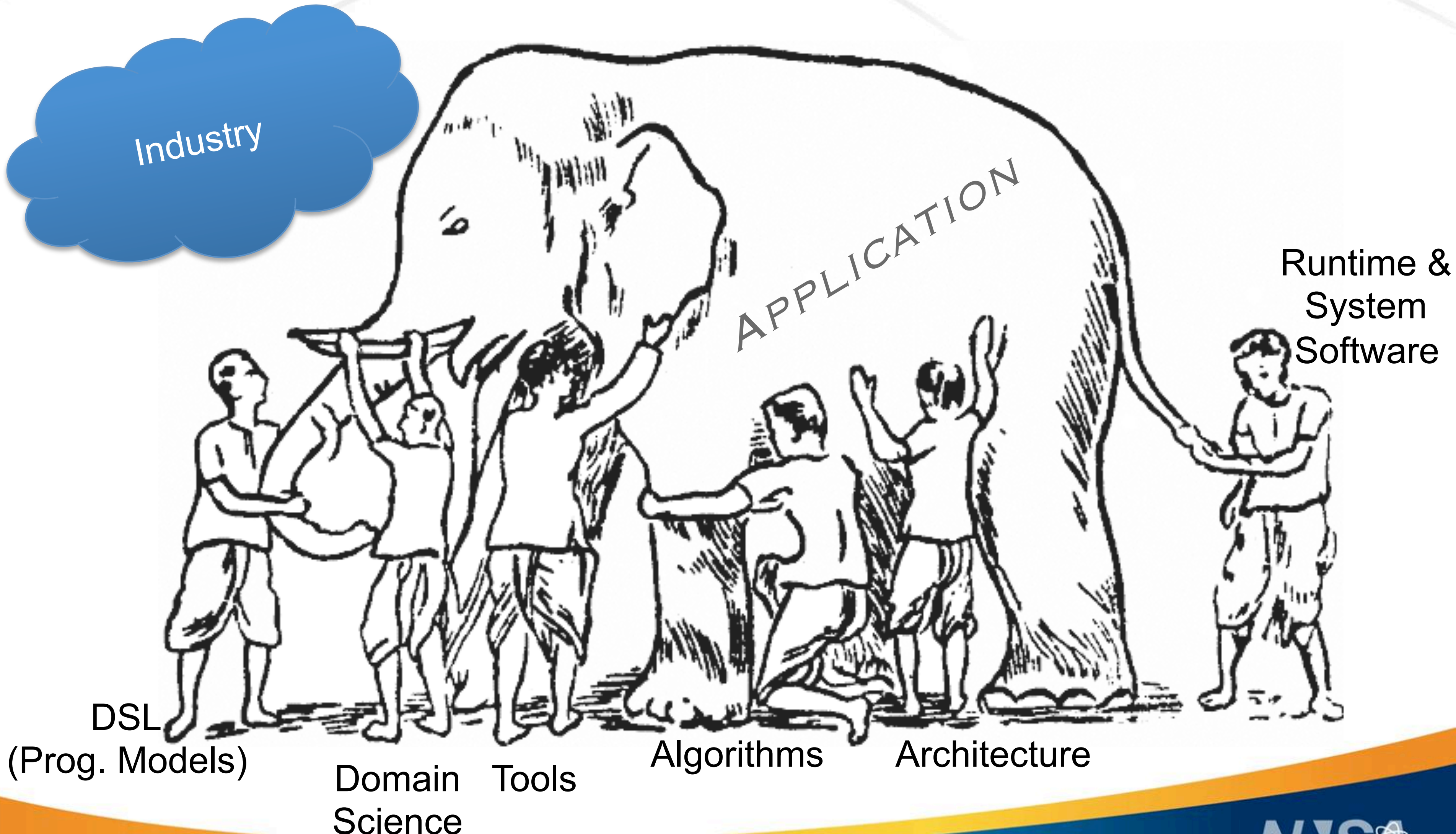
Interoperability





Fortran Application

Domain-Centric Focus is Critical



Legion Web Site

- See http://legion.stanford.edu for documentation and open-source download (from github).

Thank you

Questions?