Data centric debugging: Scaling to infinity and beyond

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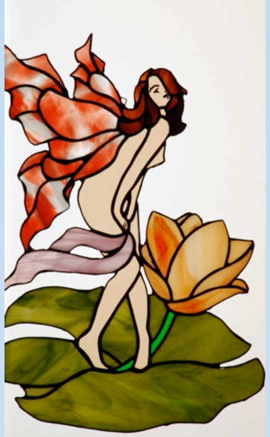
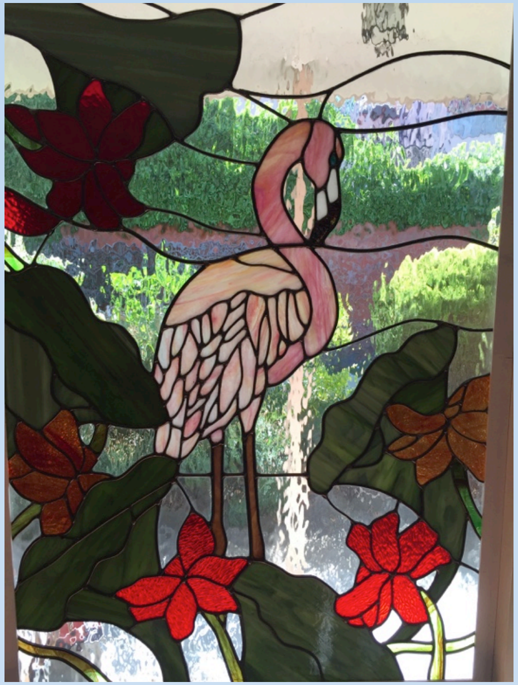
Bob Moench (Cray)
Andrew Gontarek (Cray)

Are you serious???

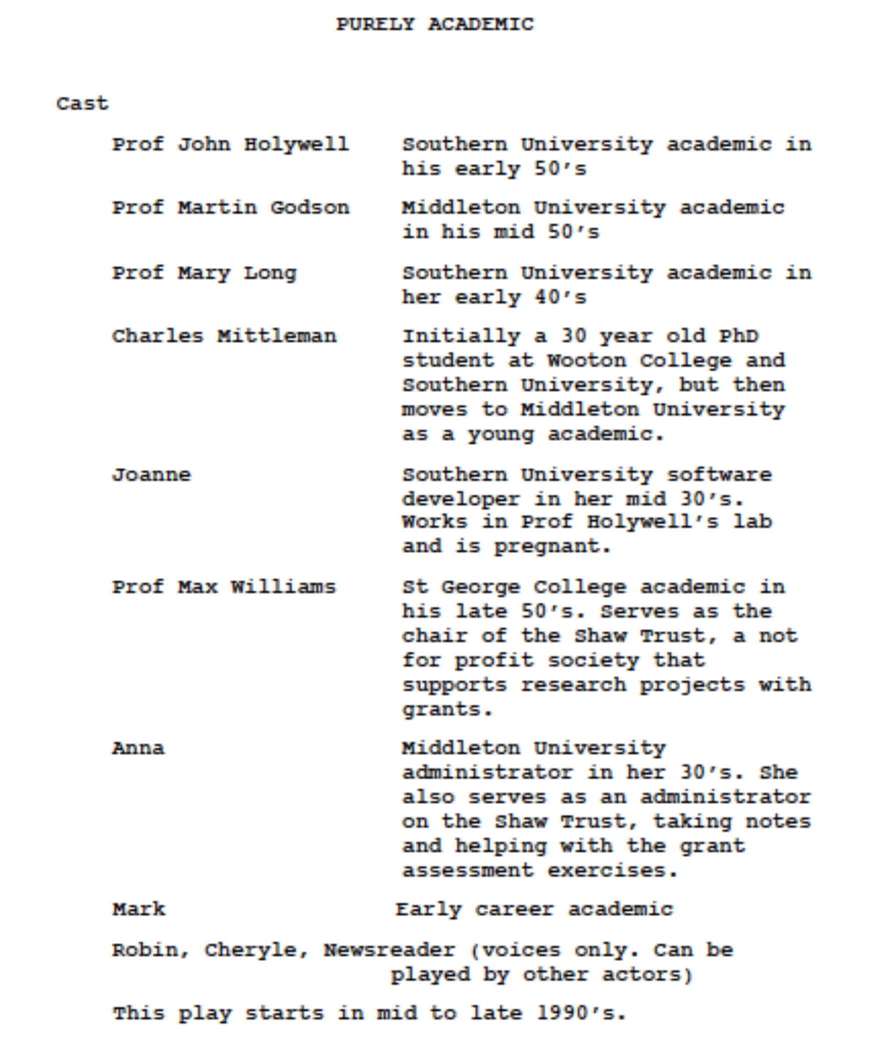
AN AFTER DINNER TALK ABOUT DEBUGGING?

“Windows on the Universe?”





Purely Academic



PURELY ACADEMIC

Cast

Prof John Holywell   Southern University academic in his early 50's

Prof Martin Godson   Middleton University academic in his mid 50's

Prof Mary Long   Southern University academic in her early 40's

Charles Mittleman   Initially a 30 year old PhD student at Wooton College and Southern University, but then moves to Middleton University as a young academic.

Joanne   Southern University software developer in her mid 30's. Works in Prof Holywell's lab and is pregnant.

Prof Max Williams   St George College academic in his late 50's. Serves as the chair of the Shaw Trust, a not for profit society that supports research projects with grants.

Anna   Middleton University administrator in her 30's. She also serves as an administrator on the Shaw Trust, taking notes and helping with the grant assessment exercises.

Mark   Early career academic

Robin, Cheryle, Newsreader (voices only. Can be played by other actors)

This play starts in mid to late 1990's.

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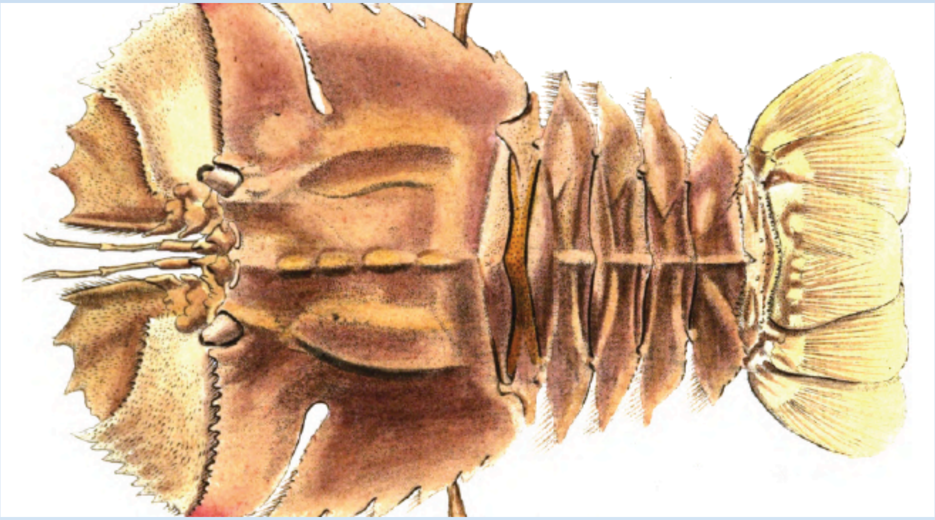
BUGS AND DINNER DON'T REALLY MIX

Larvets
ORIGINAL WORM SNAX
Mexican Spice
Net Wt. 2.1g
Larvets
ORIGINAL WORM SNAX
Cheddar Cheese

Thenus orientalis

- The United Nations' Food and Agriculture Organization prefers the name flathead lobster, while the official Australian name is Bay lobster.
  - In Australia, it is more widely known as the Moreton Bay bug after Moreton Bay, near Brisbane, Queensland.

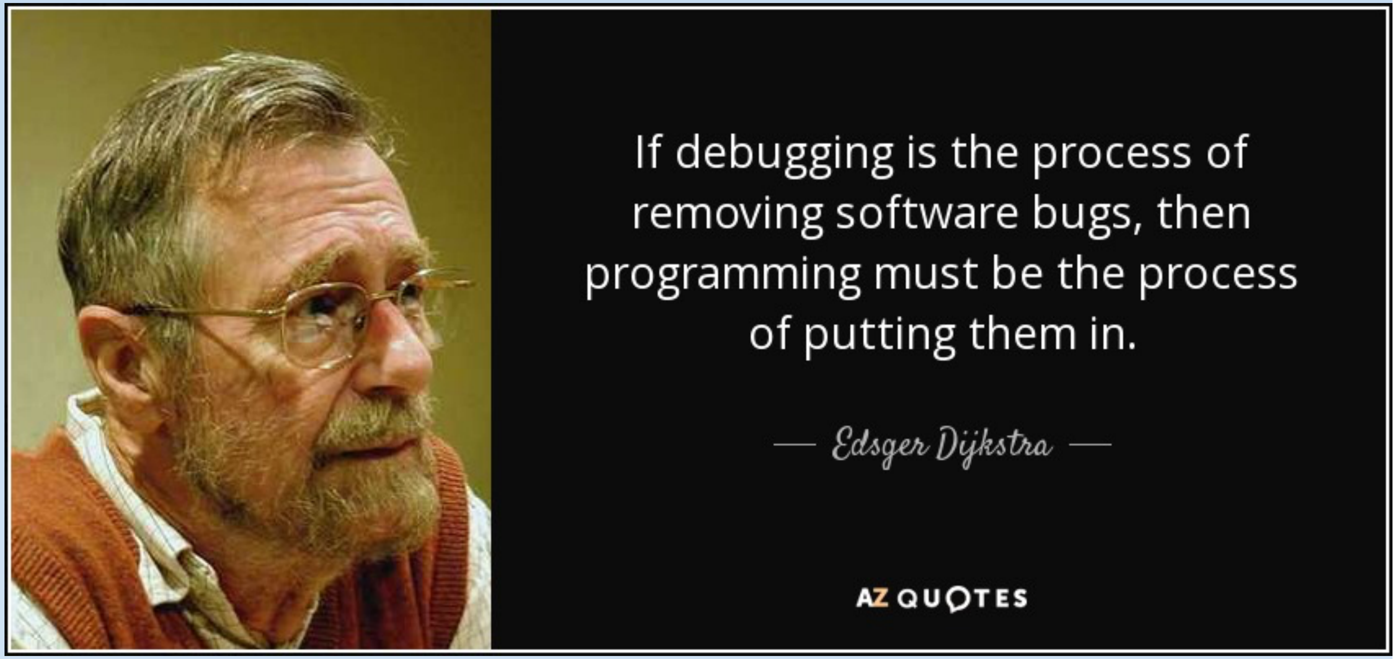
Moreton Bay
Bribie Island
Moreton Bay
BRISBANE
North Stradbroke Island
South Stradbroke Island
PACIFIC
OCEAN



How do you catch these bugs?

State of the art in debugging?

```
printf("%f %f %f\n", a[i], b[i], c[i])
a.out
```



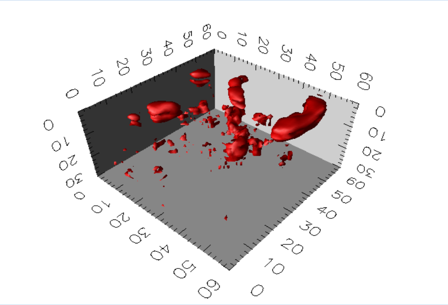
If debugging is the process of removing software bugs, then programming must be the process of putting them in.

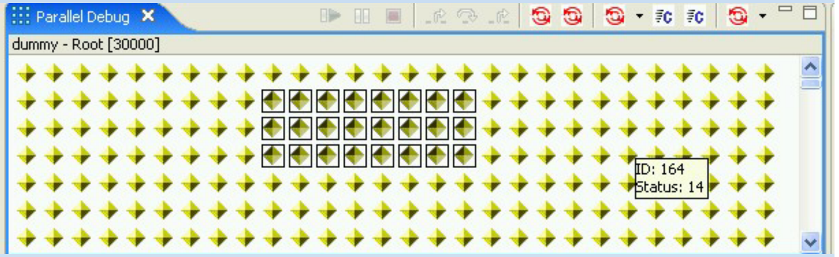
— Edsger Dijkstra —

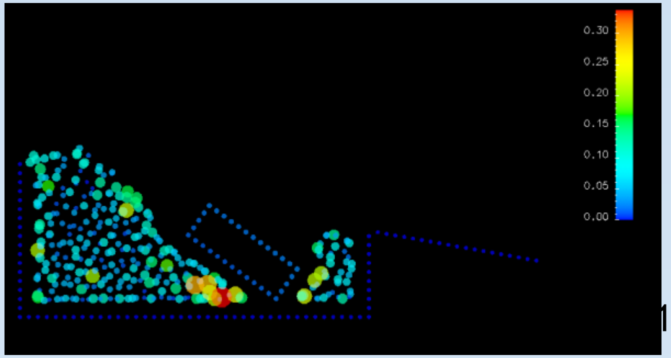
```
a.out > dumpfile; b.out > dumpfile1
diff dumpfile1 dumpfile2
```

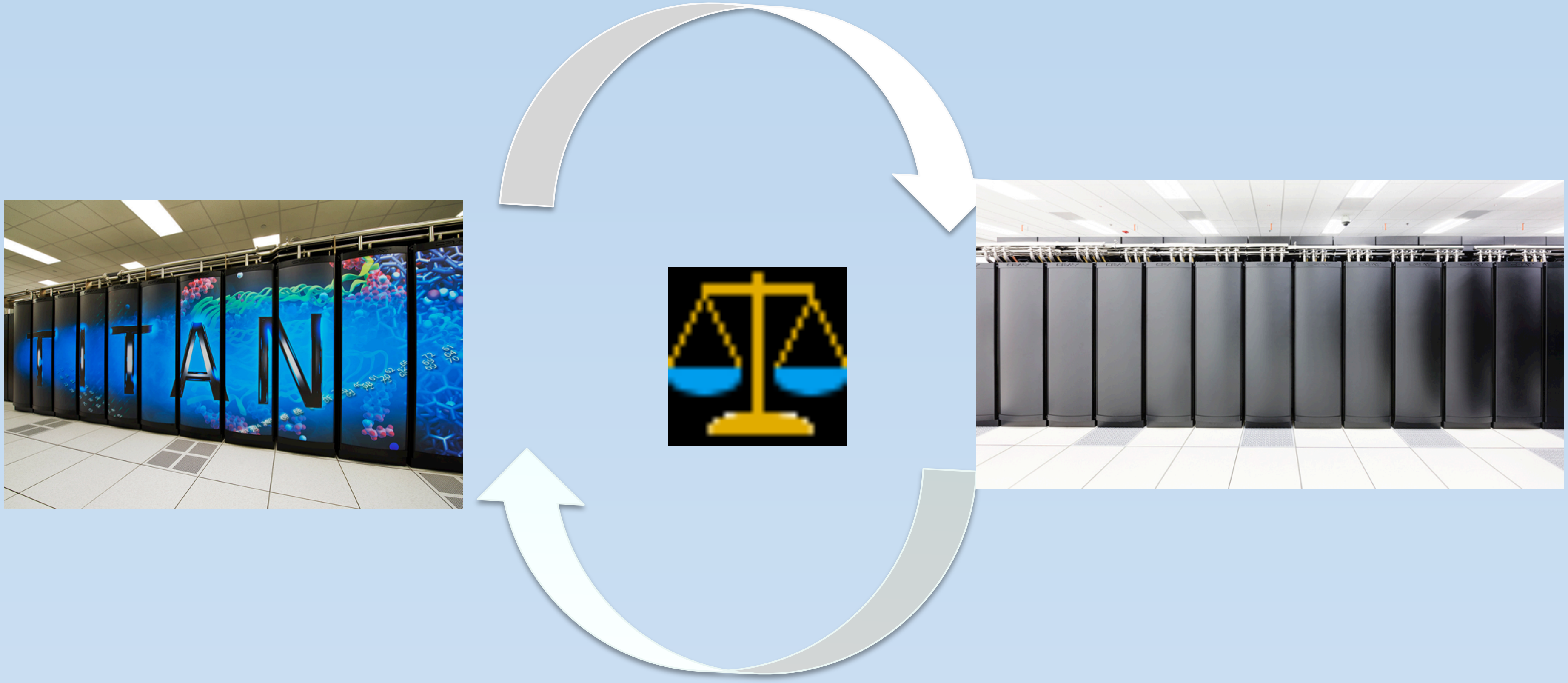
Debugging large codes

- *Cognitive* challenge
  - Large number of processes
    - Particular problems for UI
  - Large data structures
    - Infeasible to examine individual cells of multi-dimensional, floating point, structures.
  - Heterogeneity
    - A great source of errors
    - Hard to debug when do fail
- *Performance Challenge*
  - High level debugging is expensive
  - Debuggers generally don't use underlying parallel platform
- In the Exascale this just gets worse!









COMPARATIVE DEBUGGING

Debugging Evolved Applications

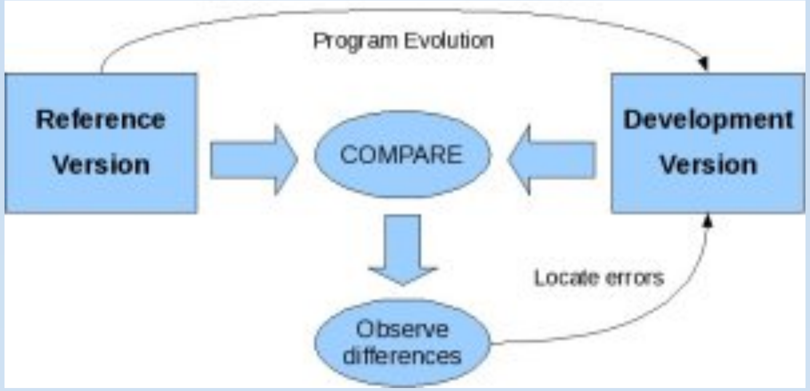
- Large codes are constantly evolving
  - User requirements
  - Underlying algorithms
  - New architectures

- Subtle errors occur often
  - Programmers spend lots of time debugging
  - Identify the source of a discrepancy
  - Follow it back to original source of deviation

Comparative Debugging

- What is comparative debugging?
  - Data centric approach
  - Two applications, same data
  - Key idea: The data should match
  - Quickly isolate deviating variables
  - Focus is on where deviations occur

- How does this help me?
  - Algorithm re-writes
  - Language ports
  - Different libraries/compilers
  - New architectures



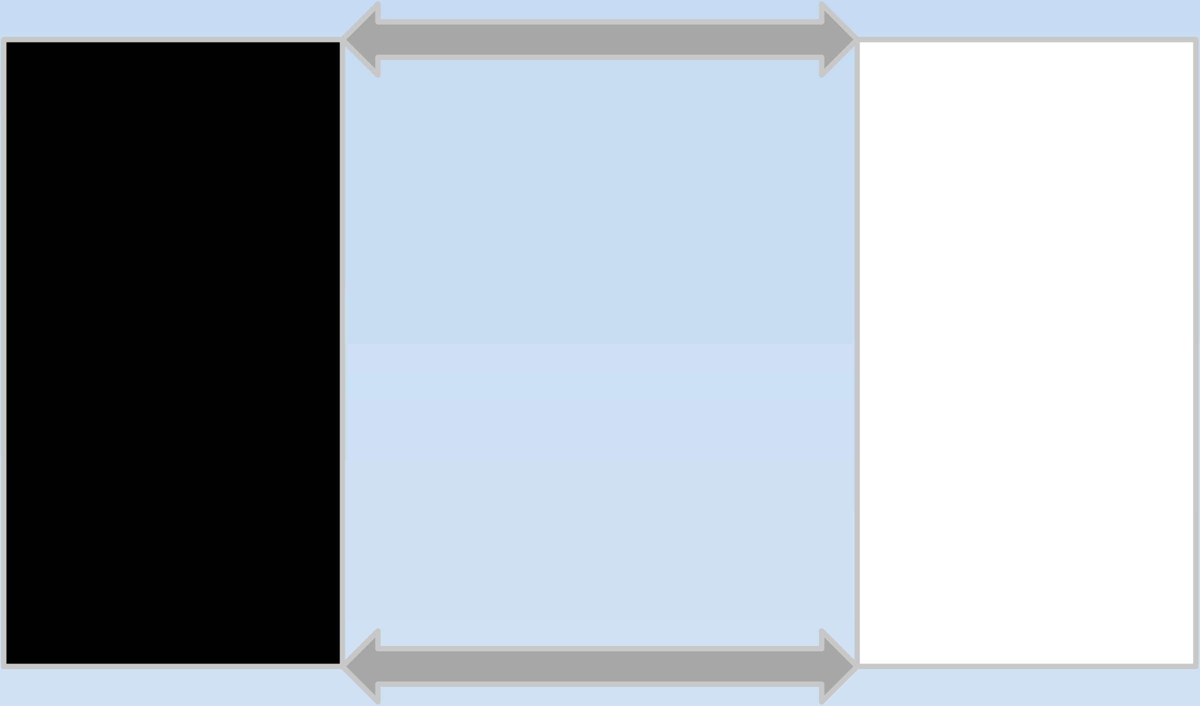
Comparative Debugging

- Specify conditions for correct behavior prior to execution
- Debugger:
  - keeps track of breakpoints
  - performs comparison automatically
- Control returned to user:
  - examination of state
  - continuation of execution

```
assert P1::big[100..199]@”file.c”:240 = P2::small@”prog.f”:300
```

Why this works?

- Iterative refinement of problem area



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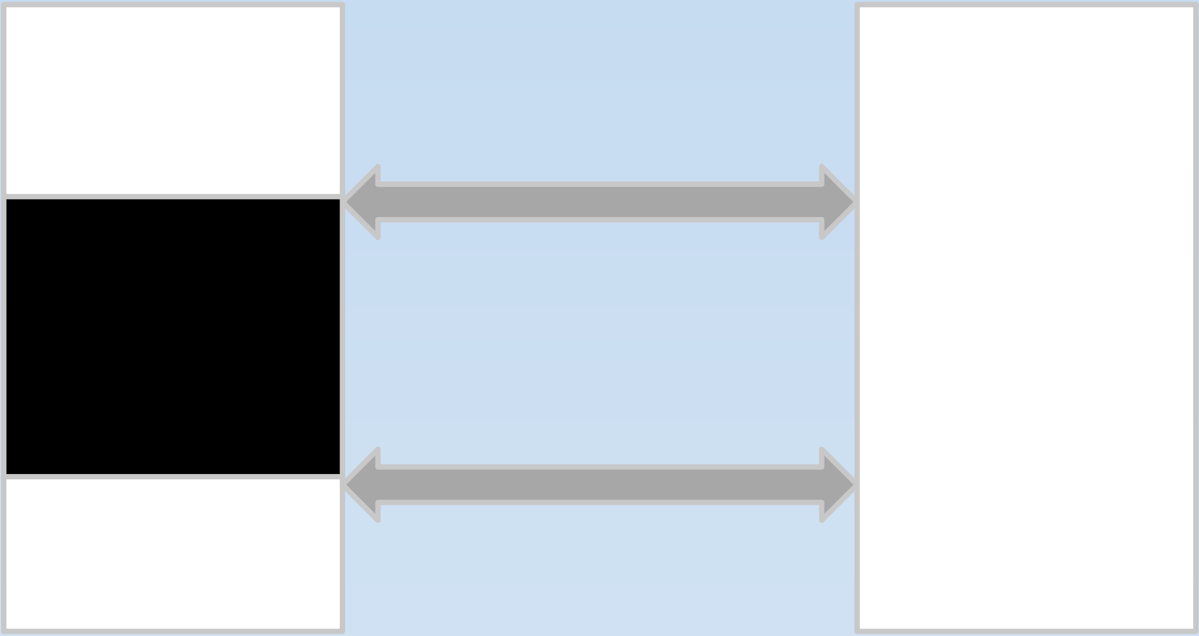

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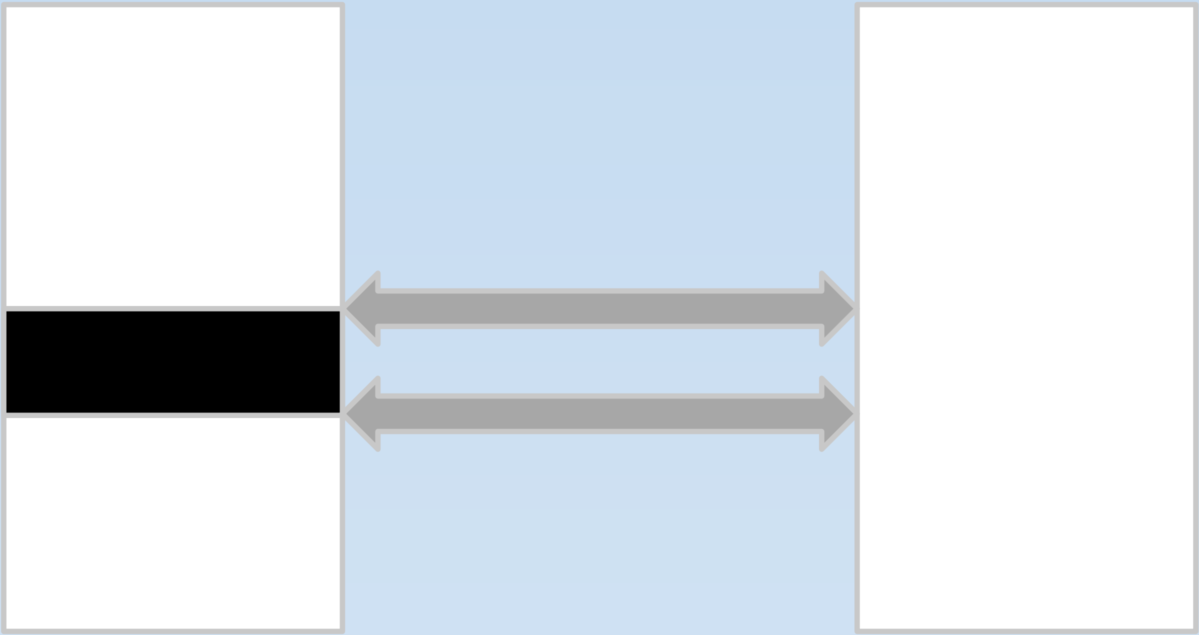

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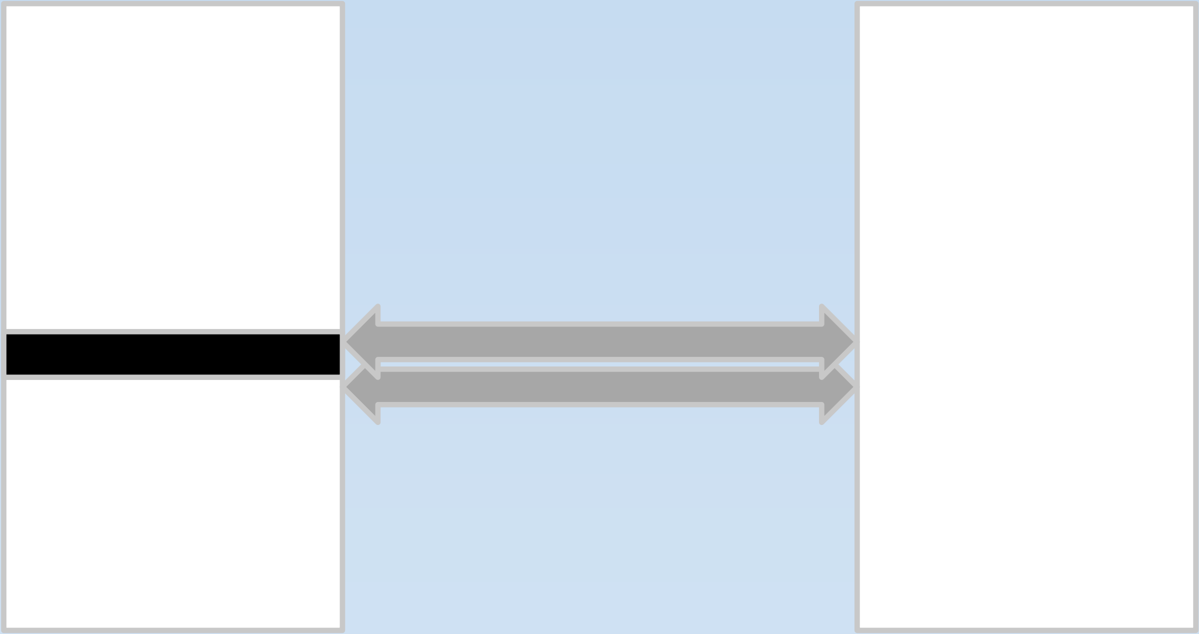
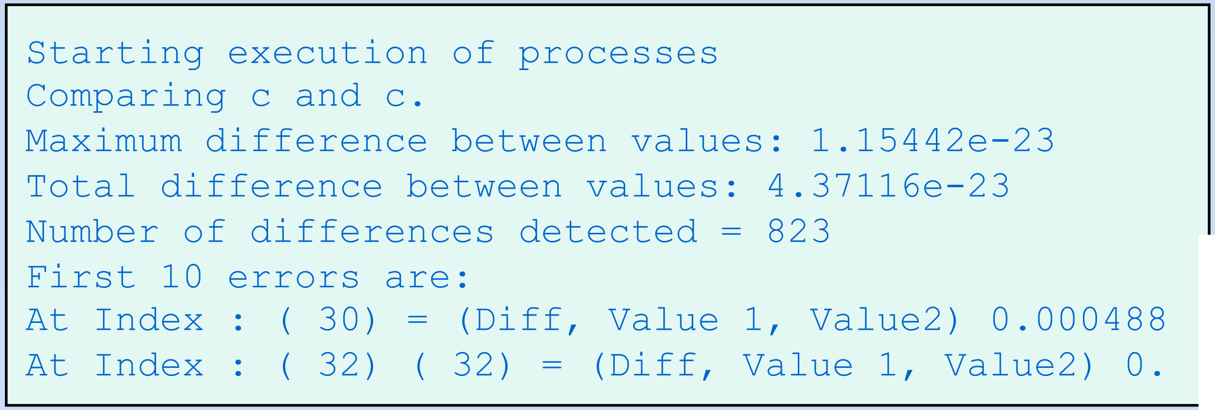


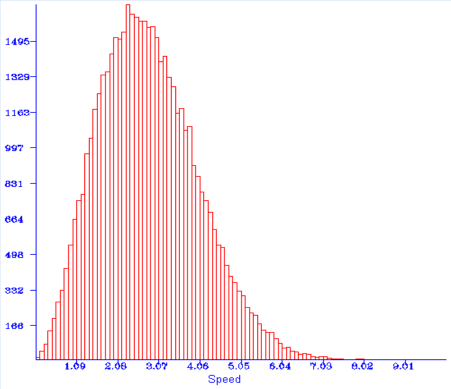
VISUALIZATION

Reporting Differences

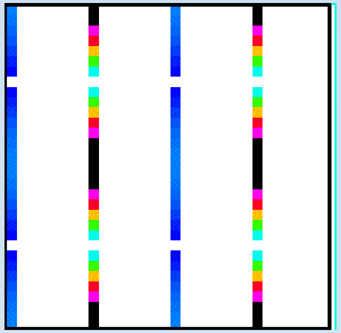
Values of scalars, small arrays



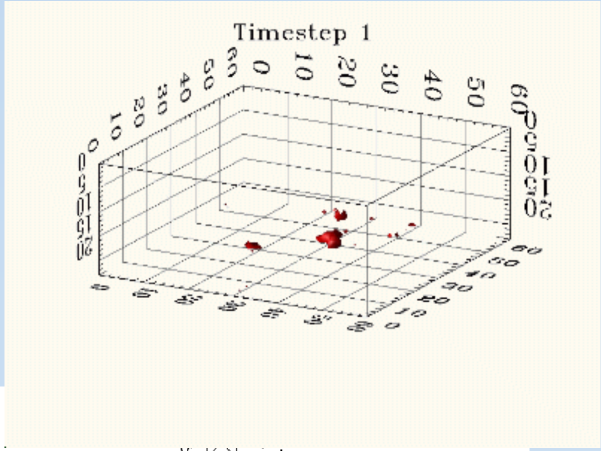
```
Starting execution of processes
Comparing c and c.
Maximum difference between values: 1.15442e-23
Total difference between values: 4.37116e-23
Number of differences detected = 823
First 10 errors are:
At Index : ( 30) = (Diff, Value 1, Value2) 0.000488
At Index : ( 32) ( 32) = (Diff, Value 1, Value2) 0.
```

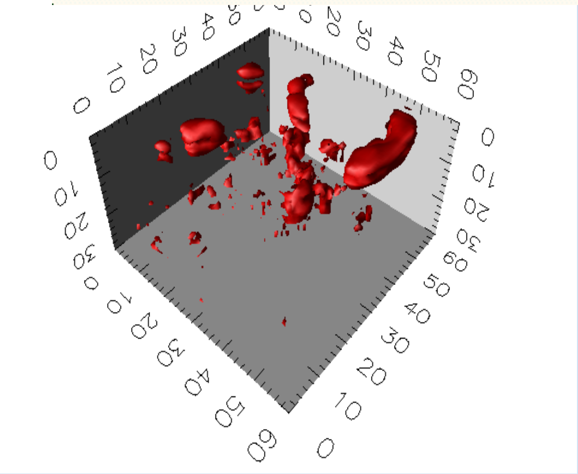


2-D pixel maps



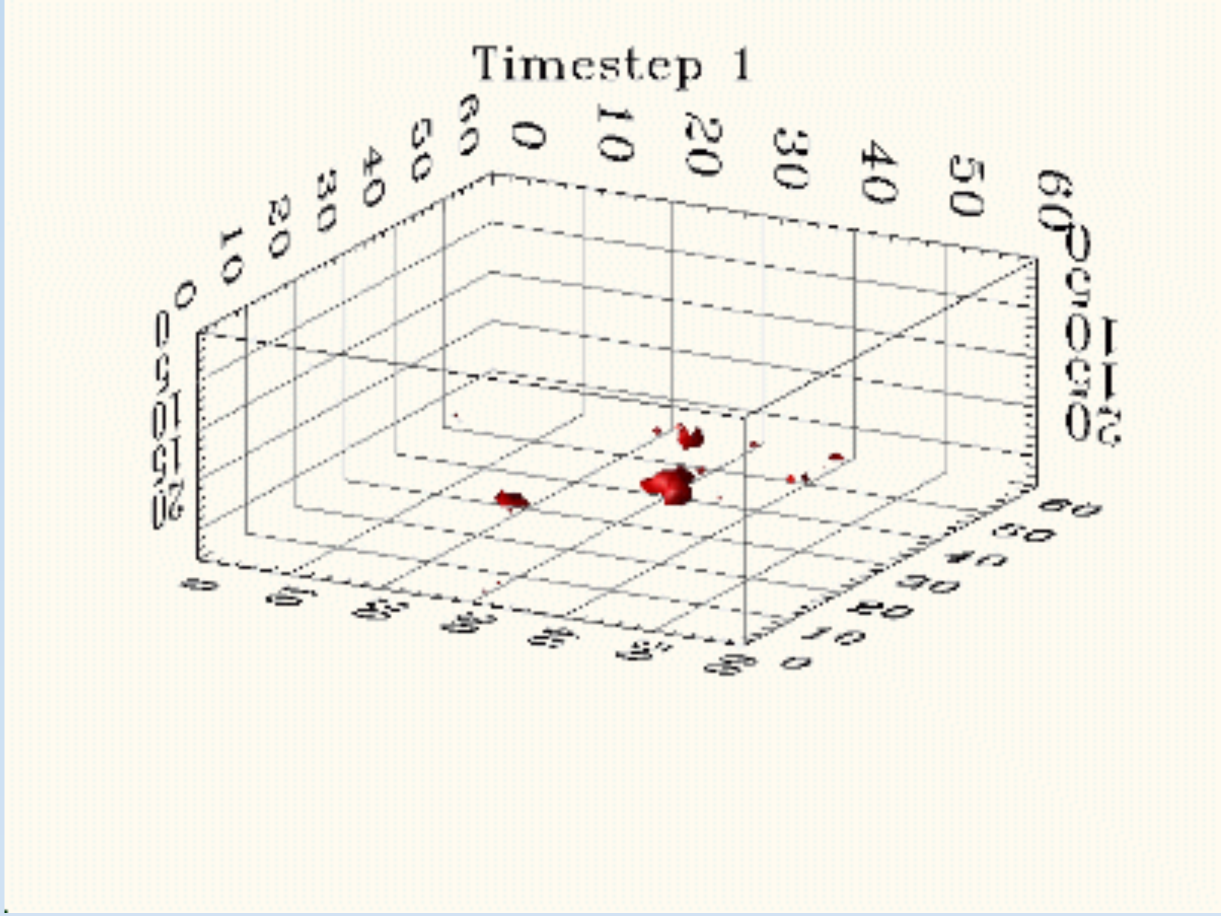
Movies





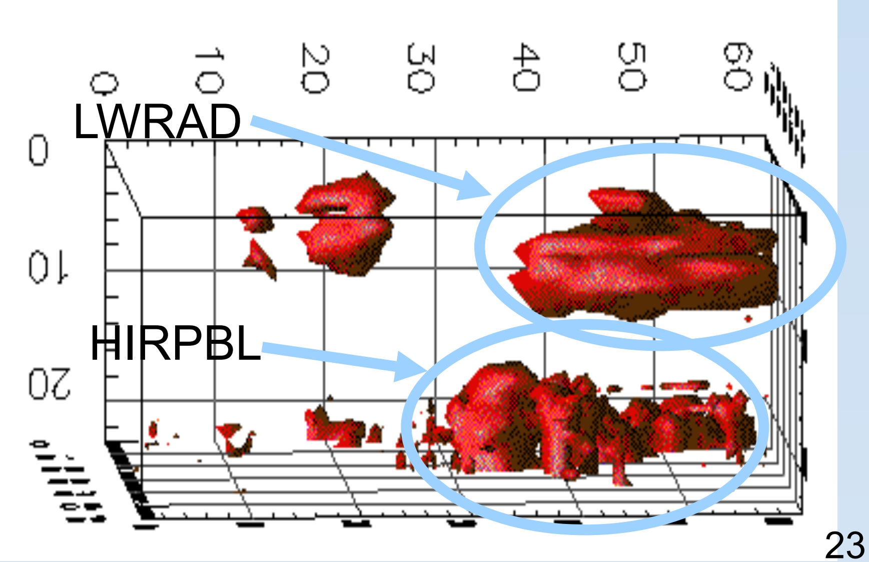
Multi-dimensional visualisation

The power of visualization

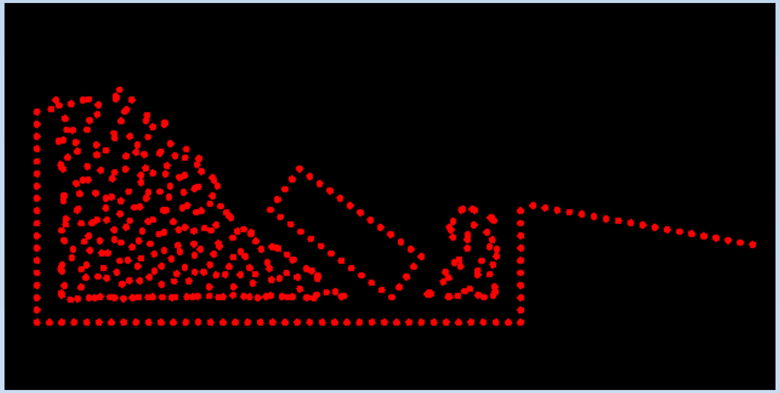


The power of visualization

- Difference in physics of planetary boundary layer
  - Computation of #steps suited to parallel execution
  - Evident in 3 dimensional visualisation
- Error in radiation time step computation
- More complete physics in long wave radiation



The power of visualization



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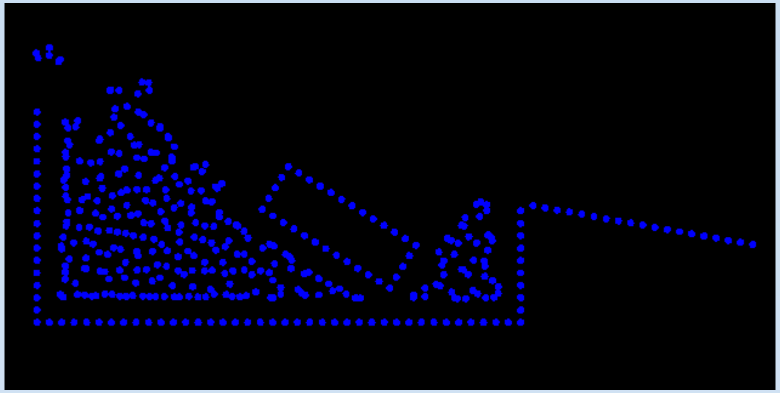

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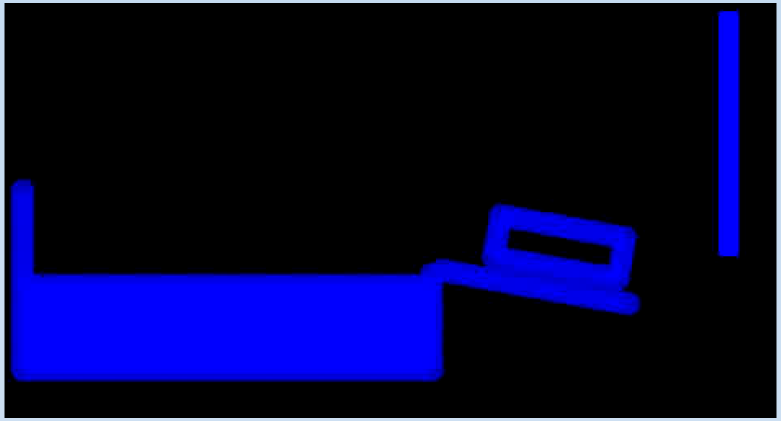
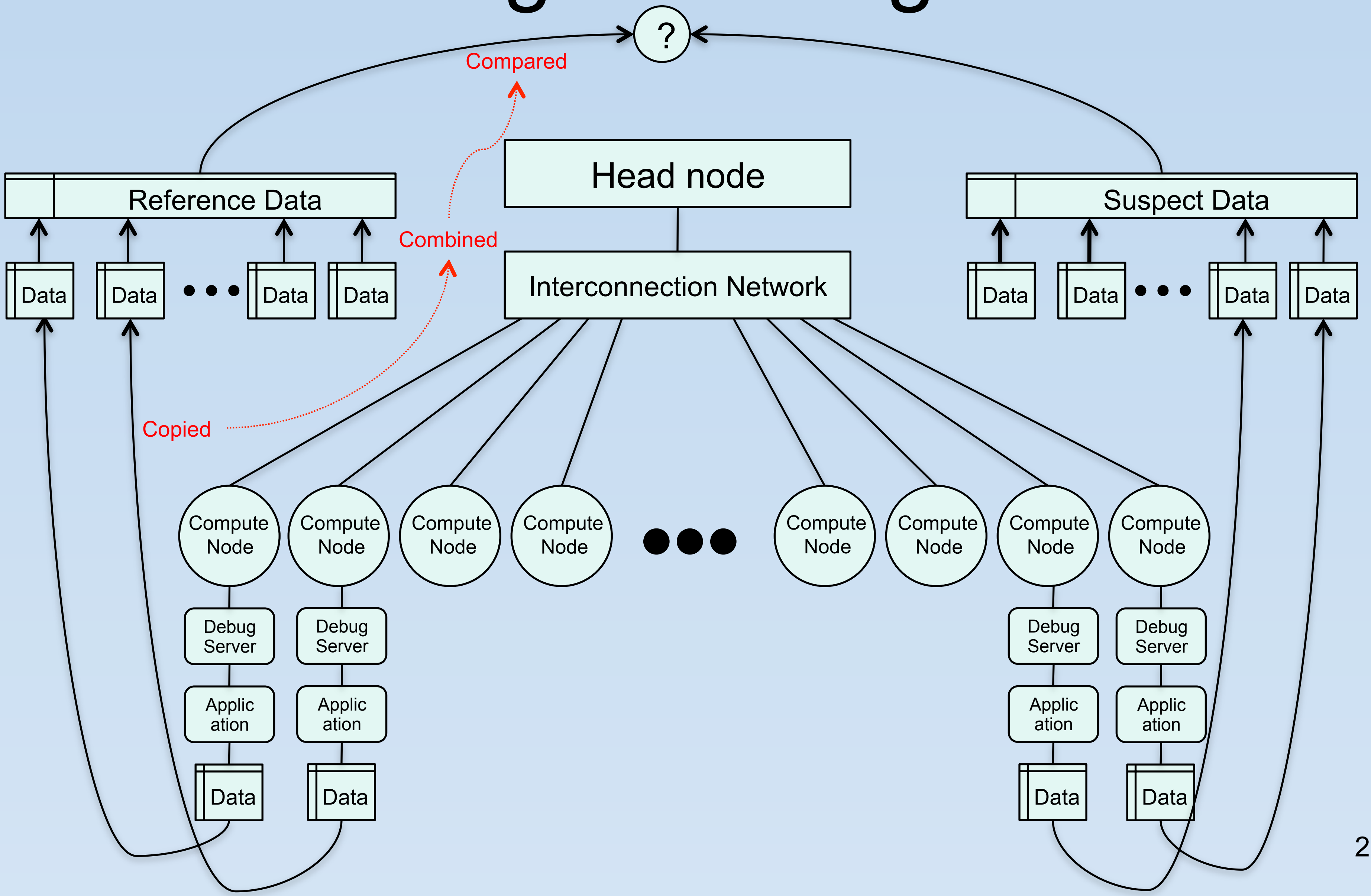
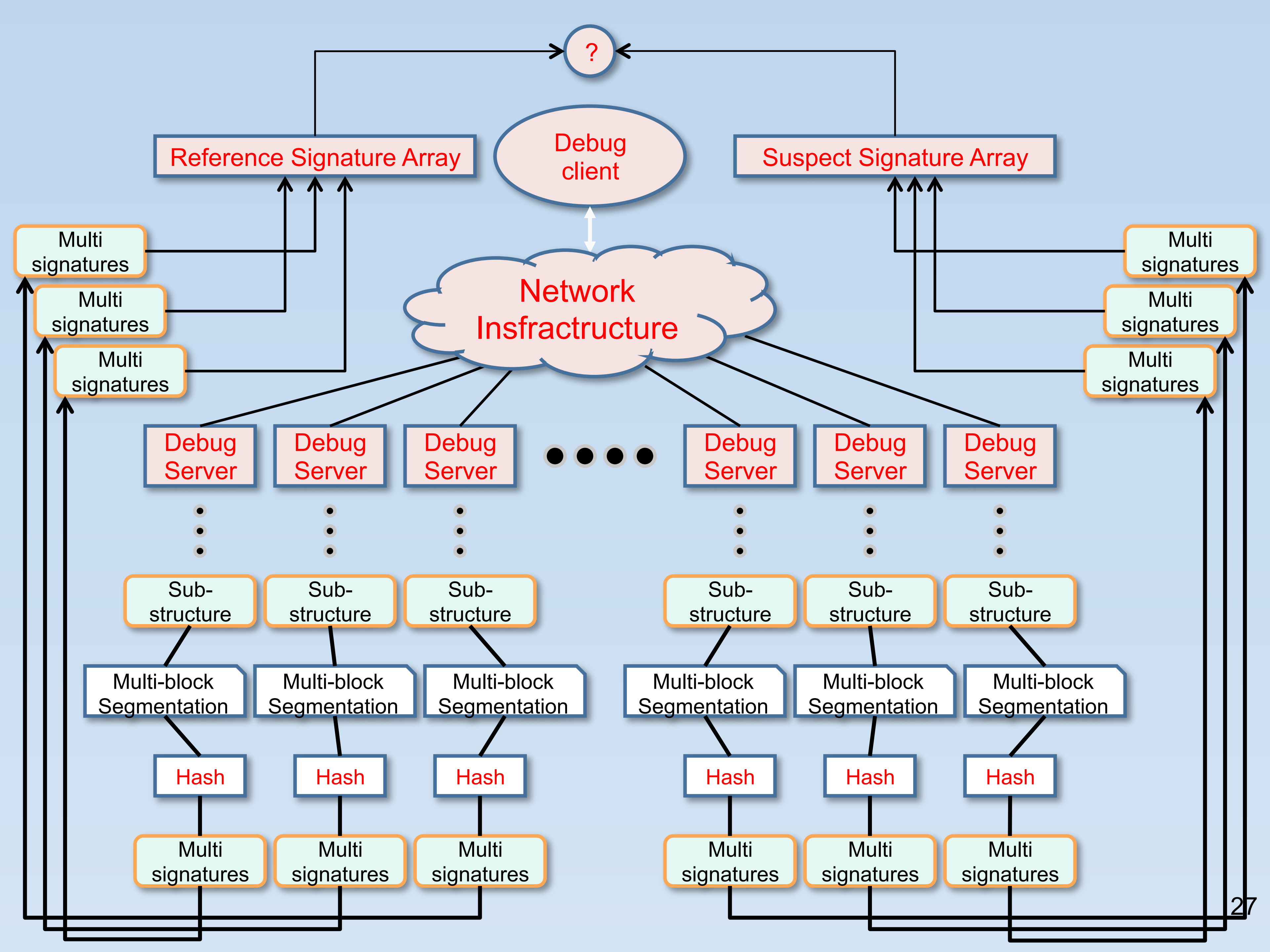


SCALABILITY

Original Design




?
Reference Signature Array
Debug client
Suspect Signature Array
Multi signatures
Multi signatures
Multi signatures
Network Insfractructure
Multi signatures
Multi signatures
Multi signatures
Debug Server
Debug Server
Debug Server
Debug Server
Debug Server
Debug Server
Sub-structure
Sub-structure
Sub-structure
Sub-structure
Sub-structure
Sub-structure
Multi-block Segmentation
Multi-block Segmentation
Multi-block Segmentation
Multi-block Segmentation
Multi-block Segmentation
Multi-block Segmentation
Hash
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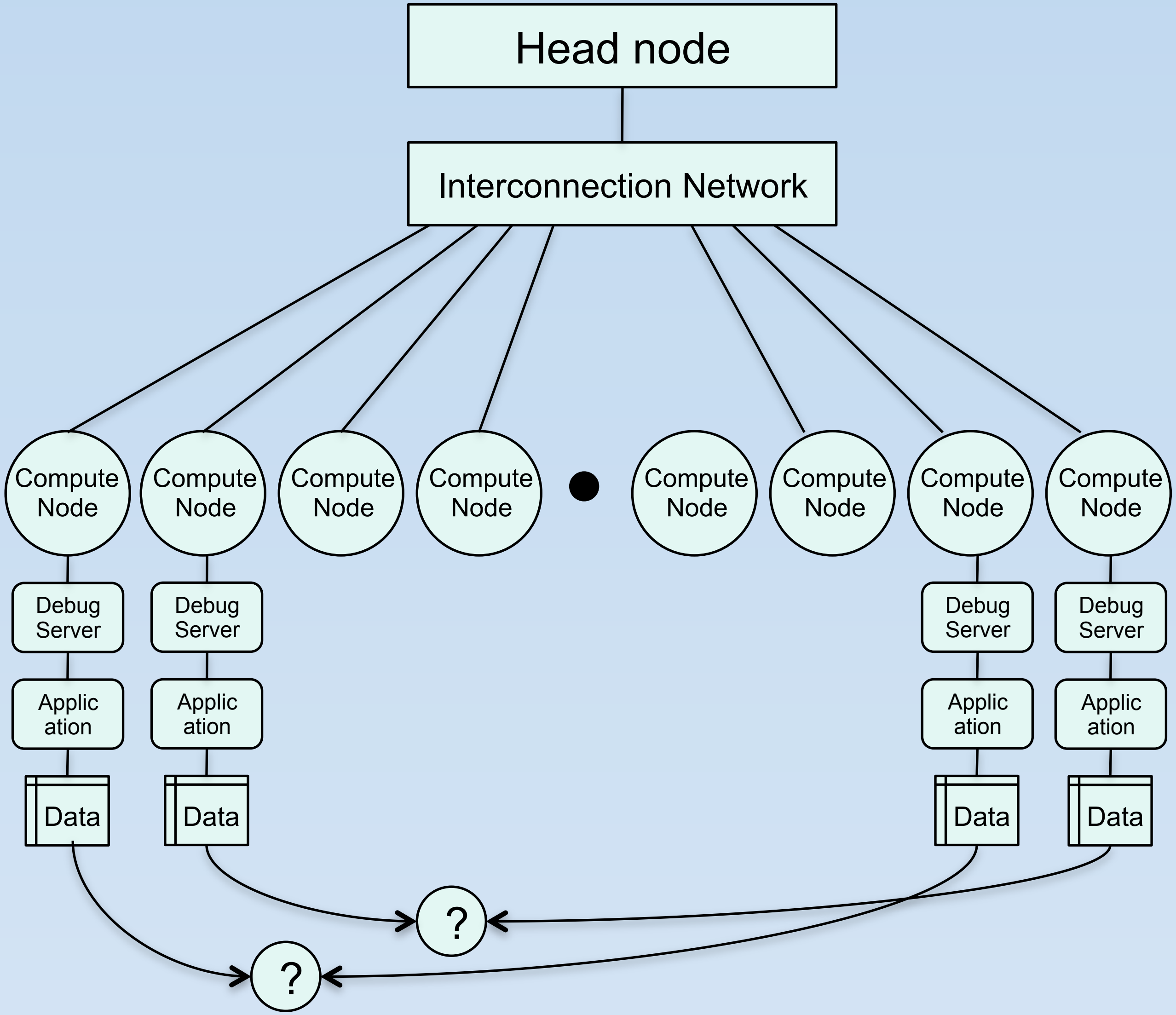
Multi signatures
Multi signatures
Multi signatures
Multi signatures
Multi signatures
Multi signatures

Point to Point protocol



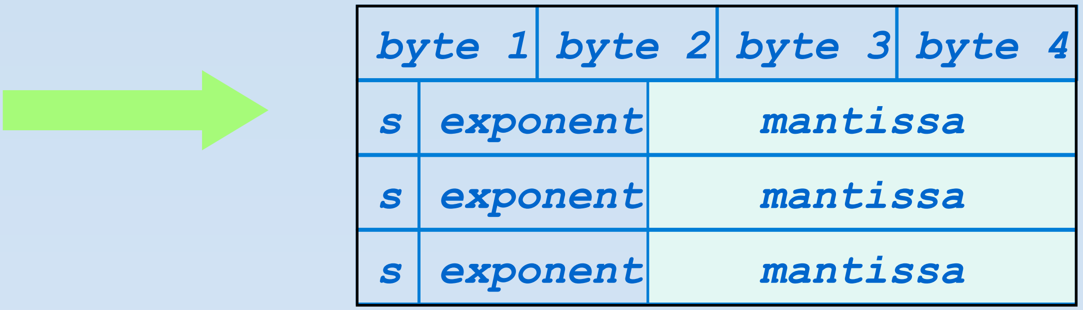
HETEROGENEITY

Architecture Independent Format

- Ability to represent data from different architectures in an architecture neutral way
- Need to perform numerical operations on data in this format
- Need to be able to convert to/from native formats

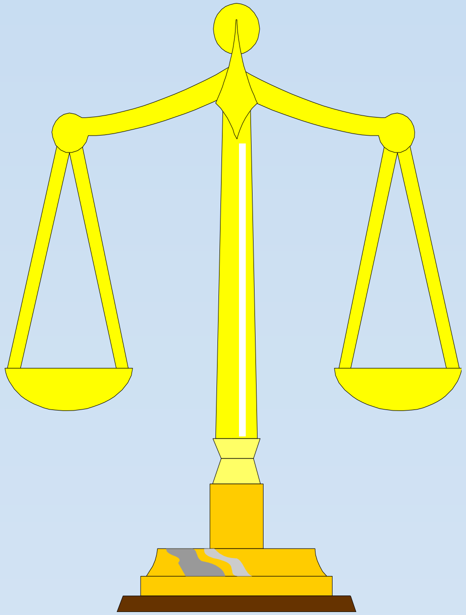
```
struct {
  int a;
  float b[3];
};
```

```
{a:is4,b:[r0..2is4]f4}
```



Flexibility in Comparisons

- Tolerances used for inexact equality
- Data structures should be:
  - type conformant (with conversion)
  - same size, but can be differing shapes
- Arrays
  - Differences allowed are:
    - offset ranges in arrays
    - ordering of indexes
    - Number of indexes
    - Language
- Dynamic data
  - Linked lists
  - Objects



Programming Languages other than C/F

- OpenACC/OpenMP
  - Sequential regions executed on CPU
  - Parallel regions offloaded to GPU
  - Data dynamically moves between CPU and GPU
  - Separated address spaces for CPU and GPU codes
  - Inconsistent precision of floating numbers across CPU and GPU
- UPC: a virtual global memory space
  - Automatically decomposing the global data across a number of SPMD threads
  - Exchanging data between threads is managed by the UPC runtime system

WITHOUT A REFERENCE CODE?

Statistical Assertions

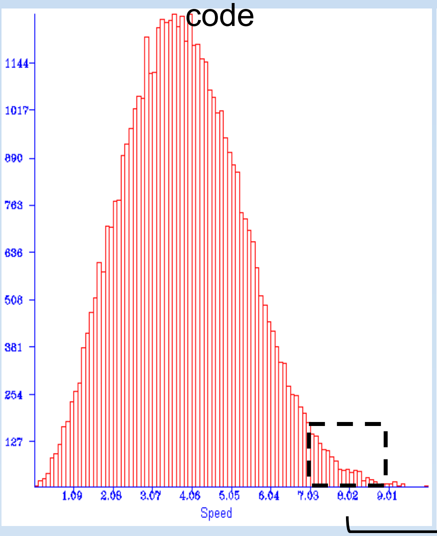
- Asserting descriptive statistics of a given dataset
  - Mean, standard deviation …
- Asserting statistical hypotheses
  - Distribution functions
  - Statistical tests
- Adjacent time steps show high data correlation
  - Can help identifying potential errors and outliers
- Asserting program states across time steps

```
history etot $a::dvalue@“thermo.cpp”:1521 10 100
set reduce stdev; compare etot < 0.1
```

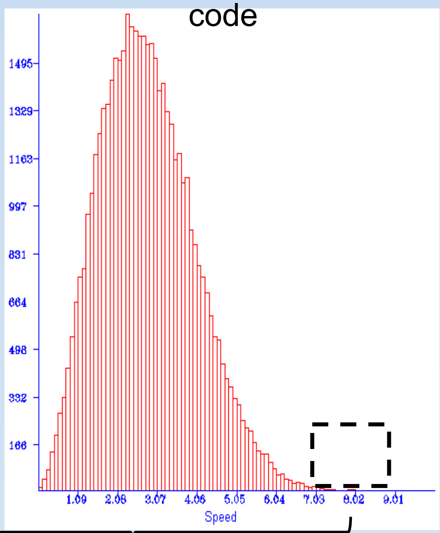
Statistical Assertions

- *Statistical parameters (mean, SD, etc)*
- *Statistical tests (T, χ^2, etc)*
- *Distributions*

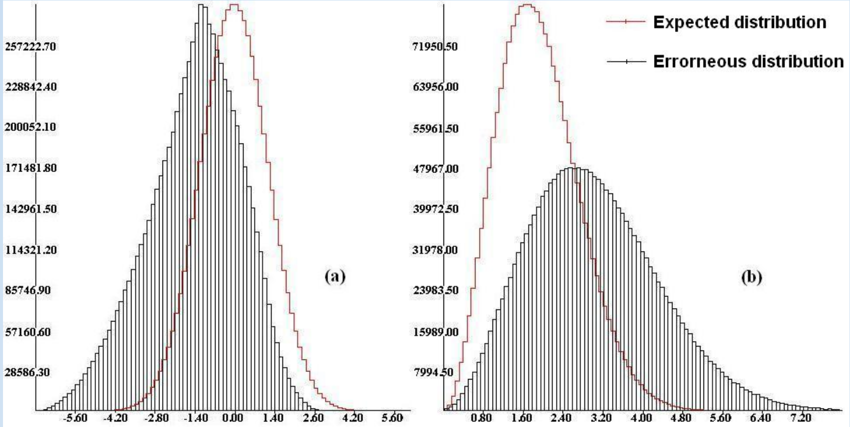
Speed histogram for incorrect code



Speed histogram for correct code



Many high speed particles



STATUS AND IMPLEMENTATION

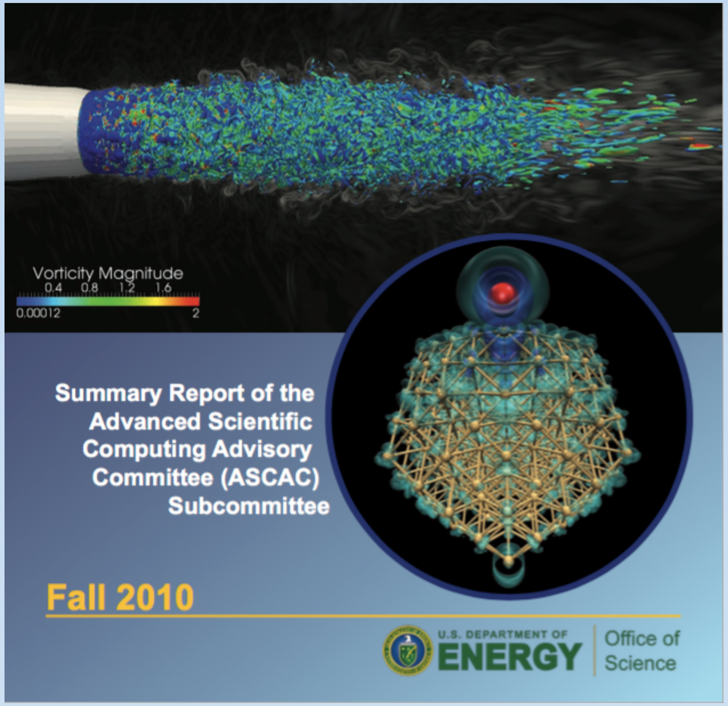
CCDB on Cray supercomputers

- Supporting Cray XE, XK, and XC supercomputers
- CCDB client: a comparative debugging interface
  - Launching parallel applications onto the back-end
  - Controlling the execution of the programs remotely
  - Compare key data structures between different applications
- CCDB server: a pluggable architecture
  - GDB: C, Fortran, and UPC programs
  - CUDA-GDB: OpenACC, OpenMP
  - MRNet
  - Scalable communication between the CCDB client and servers
  - AIF(Architecture Independent Format)
  - ‘Normalizing’ the data across platforms and languages

TO INFINITY AND BEYOND?

Exascale

- Probably big!
- Heterogeneous
- Mixed precision
- Hierarchical memories
- Algorithms
  - – Loose synchronization
  - – Fault tolerant



Summary Report of the Advanced Scientific Computing Advisory Committee (ASCAC) Subcommittee

Fall 2010

U.S. DEPARTMENT OF ENERGY | Office of Science

Debugging and Correctness

Scaling Debugging Techniques

Debugging Hybrid and Heterogeneous Architectures

Specialized Memory Systems

Domain Specific Languages

Mixed Precision Arithmetic

Adaptive Systems

Correctness Tools

Debugging and Correctness

Scaling Debugging Techniques	✔
Debugging Hybrid and Heterogeneous Architectures	✔
Specialized Memory Systems	✔
Domain Specific Languages	✔
Mixed Precision Arithmetic	✔
Adaptive Systems	?
Correctness Tools	?

✔ means some progress

Onto Dessert …

HOTLIX
Orange Flavor
with Cricket
Ingredients: Hydrogenated starch hydrolysate Cricket, artificial flavoring and coloring (Red40 Yellow 6)
Net wt 1.0z

CHOCOLATE COVERED
GIANT ANTS
RICH DARK CHOCOLATE COVERED GIANT ANTS
CONTAIN ENERGY GIVING ENZYMES
FAVOURED DELICACY OF SOUTH AMERICAN INDIANS
edible.