The Next Quarter-Century at Salishan

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The vision for this conference

"…to improve communications, develop collaborations, solve problems of mutual interest, and provide effective leadership in the field of high-speed computing“

How well have we succeeded?

What will our future challenges be?

Communications

We have learned many things at this conference about:

- Monte Carlo
- Functional languages
- Big code development
- Floating point arithmetic
- Lagrangian hydrocodes
- Anthropomorphic programming
- Performance characteristics

We understand each other's language better now.

Collaborations

Salishan has been a fruitful source of collaboration:

- DOE and DOD
  - The historical alliance has remained strong here
- Labs and academia
  - In both computer and computational science
- Academia and industry
  - It’s a great place to meet people
- Labs and industry
  - Including a few “skunk works” projects
- Even labs and labs

<u>Collaboration is a prerequisite of progress</u>

Problem solving

I recall a few small examples:

- One night after dinner, Harry Jordan and I wanted to know "is Gauss-Seidel the same as red-black?"
  - Answers varied from "that can't be true" to "I hope so"
  - Outcome was the 1986 SIAM Journal paper by Harry and Loyce Adams entitled "Is SOR color-Blind?"
- Morven Gentleman and I talked to George Zimmerman about using integers (or unnormalized floats) to make parallel Monte Carlo accumulation reproducible
  - Integer accumulators showed up in George's 1986 talk
- We have also addressed big problems, like the small size and smaller clout of the supercomputer business
  - But we haven't made such things better, at least so far

Leadership

In my estimation we haven't done so well here

- Supercomputing is in deep trouble
  - Architectures — PC-based clusters dominate
  - Languages — MPI reigns supreme
  - Applications — Industry has few, arguably none
- We know there are alternatives to the status quo
  - but we throw up our hands at changing things
- Our future success is in doubt
  - Our supercomputers are impossible to use well and quite difficult to even use poorly
  - Few think "business as usual" takes us to petaflops
- We really need to do something about the situation

Activities for the next 25 years

- Continue to teach each other what we know
- Continue to collaborate on our common problems
- Work to improve high speed computing systems in:
  - Programmability
  - Breadth of applicability
  - Performance
- Work to improve understanding of the issues by others:
  - Government
  - The press

I’ll get the ball rolling by talking about programmability

What's wrong with MPI?

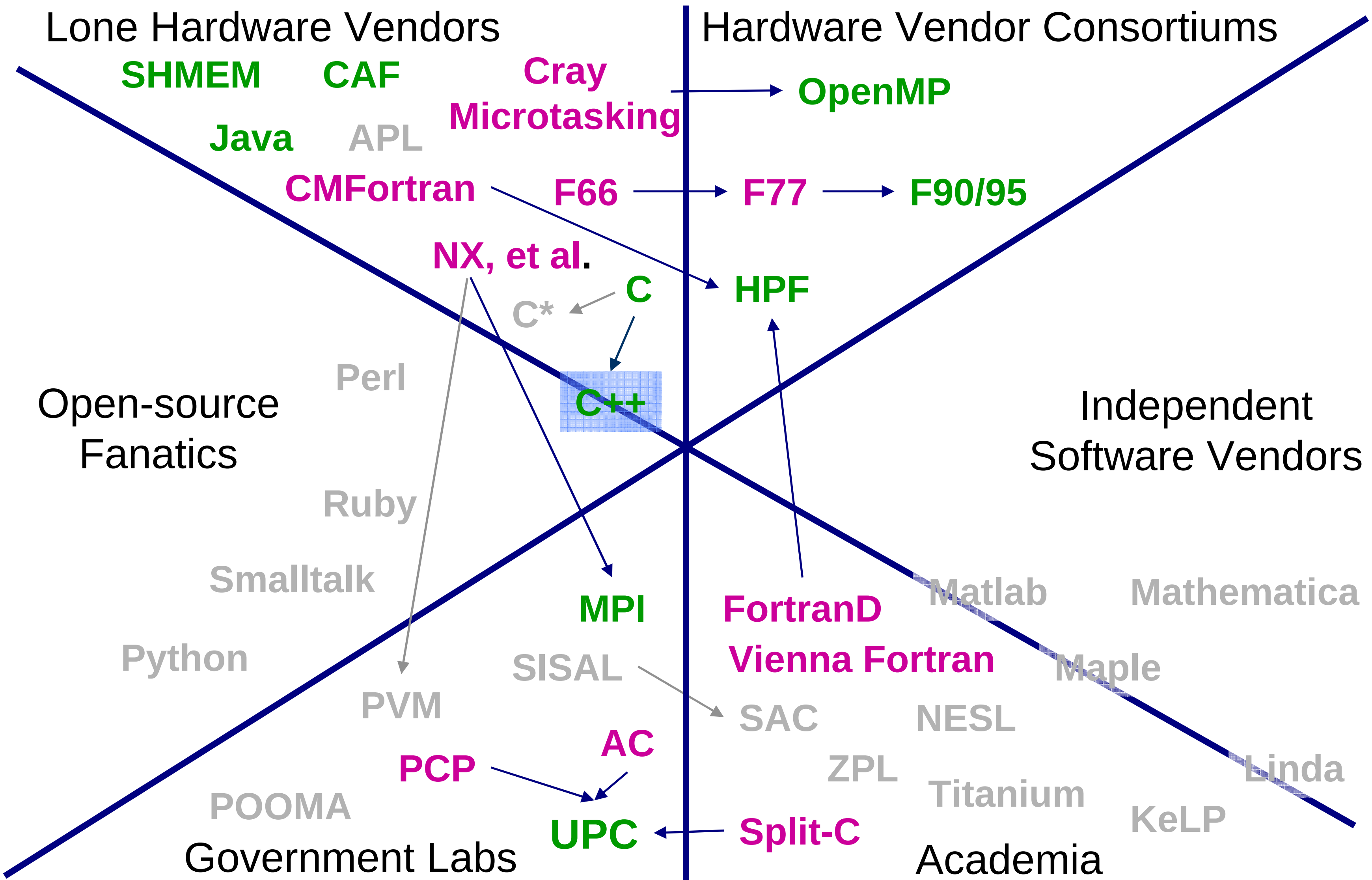
- MPI directly reflects an architectural idea
  - "Nodes" communicating via heavyweight messages
- If MPI is all there is, why build a better architecture?
  - How does the market reward your "additional features"?
- Architecture and language are inextricably linked
  - To improve either, we must improve both
- We need better programming languages:
  - To enhance programmer productivity
  - To allow fine-grain, anonymous communication
  - To enable dynamic scheduling and load balancing
  - To exploit diverse forms of parallelism
  - To improve computer architecture

We used to discuss languages here

- Fortran in all its evolutionary forms
- Functional languages, especially Id and Sisal
- Ada
- SPMD languages like The Force and OpenMP
- Object-oriented languages, especially C++, and Java
- Scripting languages such as Python
- Co-array Fortran, UPC, and Titanium

<u>The “languages” subject has become somewhat moot</u>

Where do languages come from?



Cray is designing a new language

- Its name is *Chapel*
- We have most of the compiler technology needed
  - Dependence analysis
  - Incremental interprocedural fact propagation
  - Loop nest optimizations, *e.g.* wavefronting
  - Dynamic loop nest scheduling
  - Parallelization of general reductions and recurrences
  - Parallelization of memory updates
  - Function inlining
  - Procedure annotations
  - More than just a compiler is required
- We think a new language is necessary to meet the productivity objectives of the DARPA HPCS effort
- We are hopeful it will help us sell computers

Chapel features

- Global view of computation and data structures
- Support for structured data & task parallelism
  - *data:* foralls, domains (dense & sparse arrays, sets, graphs, …)
  - *task:* co-begins, future variables, locale views, …
- Syntactic separation of concerns (locality, parallelism)
- Interprocedurally inferred latent type polymorphism
- Ability to tune for (or ignore) locality using *domains*
- User-extensible distributions, reductions, iterators, …
- Automatic resource management (threads, GC, …)
- Object-oriented features
- Generality
- An open-source implementation

Unsolved language problems

- How to ensure widespread adoption
  - An open-source implementation is necessary, at least
  - It can’t be too awful on typical hardware
- How to reconcile programmability and performance
  - A possible answer is language “telescoping” using interprocedural type inference and cloning
  - This can also help with software re-use
  - Chapel includes this notion
- How to achieve both generality and composability
  - A possible answer is using transactions to preserve invariants on program state
  - Chapel will likely experiment with this idea
  - Maybe a brief discussion of it is called for

The problem with state

- Functional languages tend to be highly composable, but there is no notion of *state* in functional languages
  - Operations on state generally don't commute
- Attempts to add state while preserving commutativity:
  - Applicative State Transition systems (Backus)
  - Monads (Wadler *et al.*)
  - M-structures (Arvind *et al.*)
- A related fact: functional programs are deterministic
  - Introducing state leads to non-determinism (*e.g.* races)
- Some kinds of nondeterminism are good
  - Any ordering that does not affect final results is OK
  - Only the programmer understands the opportunities
  - How can we tell good non-determinism from bad?

A histogramming example

```
const double in[];     //data to be histogrammed
const int f(double);   //f(x) is the bin of x
int h[];               //histogram, initially 0
for(i = 0; i < n; i++)
{   /* (∀int κ)(h[κ] = #{j|0≤j<i ∧ f(in[j])=κ}) */
  int k = f(in[i]);
  h[k]++;
}   /* (∀int κ)(h[κ] = #{j|0≤j<n ∧ f(in[j])=κ}) */
```

- Try to do this in parallel with a functional language!

Histogramming in parallel

```
const double in[];     //data to be histogrammed
const int f(double);   //f(x) is the bin of x
int h[];               //histogram, initially 0
forall i in 0..n-1
{  /* (∀int κ)(h[κ] = #{j|j∈Σ ∧ f(in[j])=κ}) */
  int k = f(in[i]);
  lock h[k];
  h[k]++;
  unlock h[k];
} /* (∀int κ)(h[κ] = #{j|0≤j<n ∧ f(in[j])=κ}) */
```

- Σ *is the set of values i processed "so far"*
- The loop instances *commute with respect to the invariant*
- Premature reads of h[ ] get non-deterministic garbage

What do the locks do?

- The locks guarantee the integrity of the invariant
  - They protect whatever makes the invariant temporarily false
- As long as invariants describe all we care about in the computation and forward progress is made, all is well
  - We have non-determinism “beneath the invariants”
  - In the example, the set Σ captures that non-determinism
- Pretty clearly, the locks need to be lightweight
  - Barriers won’t do the job
- Can we automate or at least verify lock insertion?
  - If we had a language for the invariants, maybe so
- A partial step is to let the language handle the locks
  - This is important to deal with deadlock at least
  - Efficiency is another reason

Atomic transactions on objects

```
const double in[];     //data to be histogrammed
const int f(double);   //f(x) is the bin of x
int h[];               //histogram, initially 0
forall i in 0..n-1 do
{
  int k = f(in[i]);
  with h[k] do {
    h[k]++;
  }
}
```

- This abstraction also allows compiler support and even permits implementation mechanisms other than locks

Nested, multi-object transactions

```
node *m;   //a node in an irregular adaptive mesh
/* (∀node μ)(∀node ν)(ν∈(μ->nbr)* ⇔ μ∈(ν->nbr)*) */
with *m do {               //remove *m from the mesh
  for (n = m->nbr, n != NIL, n = n->nbr){
    with *n do {           //remove link from *n to *m
      for (p = n->nbr, p != NIL, ... //etc
    }
  }
}
```

- In a naive implementation, deadlock could be commonplace
- If a sequence deadlocks or fails, preservation of the invariant requires that it be “undone”, reversing its side effects

Conclusions

- It’s been a memorable and rewarding quarter-century
- The problems we now face are more serious than ever
  - and we may even have forgotten a thing or two
- We need to continue to meet the challenges

“There is no limit to what
we can accomplish
provided
you don’t care who gets the credit”

— George A. Michael