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

Collaboration is a prerequisite of progress
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

The “languages” subject has become somewhat moot
Where do languages come from?

Lone Hardware Vendors
- SHMEM
- CAF
- Java
- APL
- CMFortran
- NX, et al.
- Perl
- Ruby
- Smalltalk
- Python
- POOMA
- PCP
- UPC

Hardware Vendor Consortiums
- Cray
- OpenMP
- Microtasking
- F66
- F77
- F90/95
- HPF
- C
- C*
- C++
- FortranD
- Vienna Fortran
- MPI
- SISAL
- AC

Academia
- Mathematica
- Maple
- Matlab
- Linda
- Titanium
- KeLP
- Split-C
- SAC
- ZPL
- NESL
- SISAL
- Titanium

Open-source Fanatics
- Java
- Microtasking
- NX, et al.
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 k = f(in[i]);
    h[k]++;
}

• Try to do this in parallel with a functional language!
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
{
    /* (\forall \text{int } \kappa)(h[\kappa] = \#\{j|j \in \Sigma \land f(in[j])=\kappa\}) */
    int k = f(in[i]);
    lock h[k];
    h[k]++;
    unlock h[k];
}
/* (\forall \text{int } \kappa)(h[\kappa] = \#\{j|0 \leq j < n \land f(in[j])=\kappa\}) */

\cdot \Sigma \text{ is the set of values i processed “so far”}
\cdot \text{The loop instances commute with respect to the invariant}
\cdot \text{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
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