Why Compilers Have Failed To Support HPC Programmers and What Can We Do About It

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Impact of Languages and Compilers

- Languages and Compilers have drastically improved the programmer productivity
  - Ease of expression and construction of large programs
    - High Level Languages
    - Object Oriented Languages
  - Elimination of many classes of bugs
    - Managed Memory
    - Type Safety
  - Fully portable across all hardware
    - Instruction Level Parallelism
- …except in high performance programming!

Impact of Languages and Compilers in parallelism

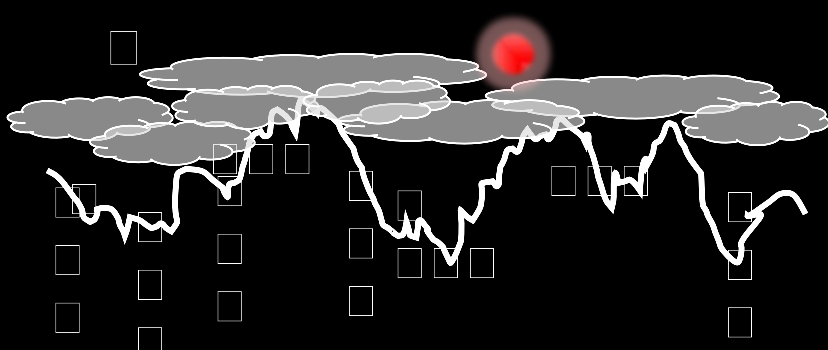
- Parallel programming still feels like assembly level programming
  - All the hardware features are fully exposed
    - Need to explicitly manage → no portability
  - Many classes of nasty bugs
    - Deadlocks, race conditions etc.

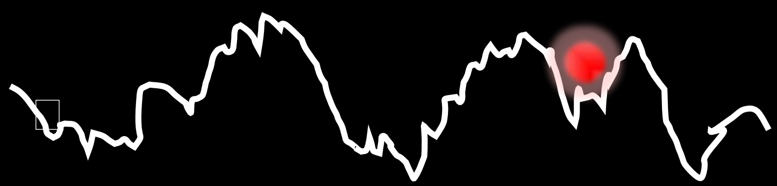
Success Criteria for a Compiler

1. Effective
2. Stable
3. Portable
4. Scalable
5. Simple

1: Effective

- Compiler optimizations has to select the best choice among all possibilities, but…
  - Options are obscured
    - Impossible to identify, evaluate, select
  - Options not available
    - In a local minima
    - Heroic effort needed to get out





- To be effective compiler
  - Restrict the choices when a property is hard to automate or constant across architectures of current and future → expose to the user
  - Expose ones that are automatable and variable → hide from the user

2: Stable

- Simple change in the program should not drastically change the performance!
  - Otherwise need to understand the compiler inside-out
  - Programmers want to treat the compiler as a black box

3: Portable

- Work on the spectrum of current architectures
  - Terrascale, petascale
- Need to be “Future-Proof”
  - Ex: heterogeneous architectures
- Cannot hardcode parameters that’ll change

4: Scalable

- Works well on your small cluster is good
- …but will it work the same work on Jaguar?
- How about the exascale machines?

5: Simple

- Aggressive analysis and complex transformation lead to:
  - Buggy compilers!
    - Programmers want to trust their compiler!
    - How do you manage a software project when the compiler is broken?
  - Long time to develop
- Simple compiler $\Rightarrow$ fast compile-times
- Current compilers are too complex!

Compiler	Lines of Code
GNU GCC	~ 1.2 million
SUIF	~ 250,000
Open Research Compiler	~3.5 million
Trimaran	~ 800,000
StreamIt	~ 300,000

A Success Story: Register Allocation

- Effective
  - Every architecture has registers at the bottom of the memory hierarchy
  - All the registers were hidden from the users
    - Early C let the users bound registers to variables, but now hidden from the user
  - Users are exposed to identifying reg allocatable variables (i.e. with volatile)
  - Allocating a variable to a register reduce mem bandwidth → clear winner
- Stable
  - Local optimization. If you miss one, no global consequence
- Portable
  - Variations between hardware (# of regs, special purpose regs) is exposed and managed by the compiler
- Scalable
  - Local problem, out of Moore's curve → scaling is not an issue
- Simple
  - Graph coloring and spilling heuristics is (now) trivial

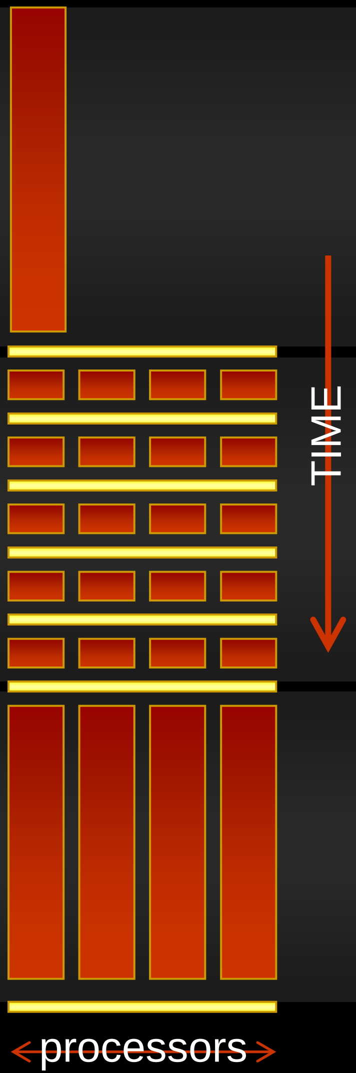
The Dream: Automatic Parallelization

- Identify loops where each iteration can run in parallel
  - DOALL parallelism
- What Matters
  - Parallelism Coverage
  - Parallelism Granularity

```
TDT = DT
 MP1 = M+1
 NP1 = N+1
 EL = N*DX
 PI = 4.D0*ATAN(1.D0)
 TPI = PI+PI
 DI = TPI/M
 DJ = TPI/N
 PCF = PI*PI*A*A/(EL*EL)
```

```
 DO 50 J=1,NP1
    DO 50 I=1,MP1
         PSI(I,J) = A*SIN((
         I-.5D0)*DI)*
         SIN((J-.5D0)*DJ)
         P(I,J) = PCF*(COS(2.D0)
CONTINUE
```

```
 DO 60 J=1,N
      DO 60 I=1,M
         U(I+1,J) = -(PSI(I+1,J+1)
         -PSI(I+1,J))/DY
         V(I,J+1) = (PSI(I+1,J+1)-
         PSI(I,J+1))/DX
 CONTINUE
```



Why Automatic Parallelism Failed

- Lack of Effectiveness
  - Sequential description obscures inherent parallelism
  - Need heroic analysis
- Lack of Scalability
  - Amdhal's law: increased parallelism → more parallelism coverage
  - Need more heroic analysis
- Lack of Stability
  - Granularity of Parallelism
  - Small changes have a large impact
    - Parallelize one additional statement → change the granularity
  - Needs even more heroic analysis
- Lack of Simplicity
  - All these heroic analyses → A hugely complex compiler

The Reality: MPI + X

- All the burden on the programmer
  - Parallelization
  - Computation and Data partitioning
  - Communication orchestration

Why Compilers will not succeed with MPI+X

- Lack of Effectiveness
  - Programmer binds most important decisions
  - Not too much choice exposed to the compiler
- Lack of Portability
  - Data partitioning and communication orchestration
    - Early binding to the given architecture
    - Heroic analysis will be needed to change automatically
  - MP+OpenMP+Cuda+???
    - The partitioning match the current components
    - Heterogeneous mix will change in the future
- Lack of Scalability
  - Hard to scale when hard bound to current machines

If we have a Revolution, what should it be?

- A new programming model/language that….
  - Will take much of the burden of away from the programmer
    - Managing the architectural features
    - Tuning for performance
  - Will make some classes of hard problems completely go away
    - No race conditions or deadlocks
  - Will make is possible for the compiler to “do the right thing”
    - Able to optimize by taking advantage of all the capabilities
    - Able to provide performance portability for current and future machines
  - Will make is possible for experts to “help” the compiler
    - A performance guru can provide patterns and transformations that are specific to the given application
- A new compiler that will not let the programmers down!

Selecting between the programmer and the compiler

- Let the programmer handle features that are impossible to automate
  But…make them constant across all current and future architectures
  - Get the programmers to expose maximum concurrency inherent to the algorithm
  - Get the programmers to over partition the data (perhaps hierarchically)
  - Get the programmer to provide more than one choice of algorithm and data partition

Selecting between the programmer and the compiler

- Let the compiler handle features that change across architectures
  - Managing parallelism
  - Managing heterogeneity
  - Managing data partitioning
  - Managing communication orchestration

What happens if these are still too hard for the compiler to handle?

- Provide hooks so expert performance gurus can intervene when needed
- Invest in developing compiler technology
- Wait patiently until the compiler people get it(hopefully!) working

Problem with High Performance Languages

- There are no new ideas in high performance languages
  - No new constructs
  - No new programming models

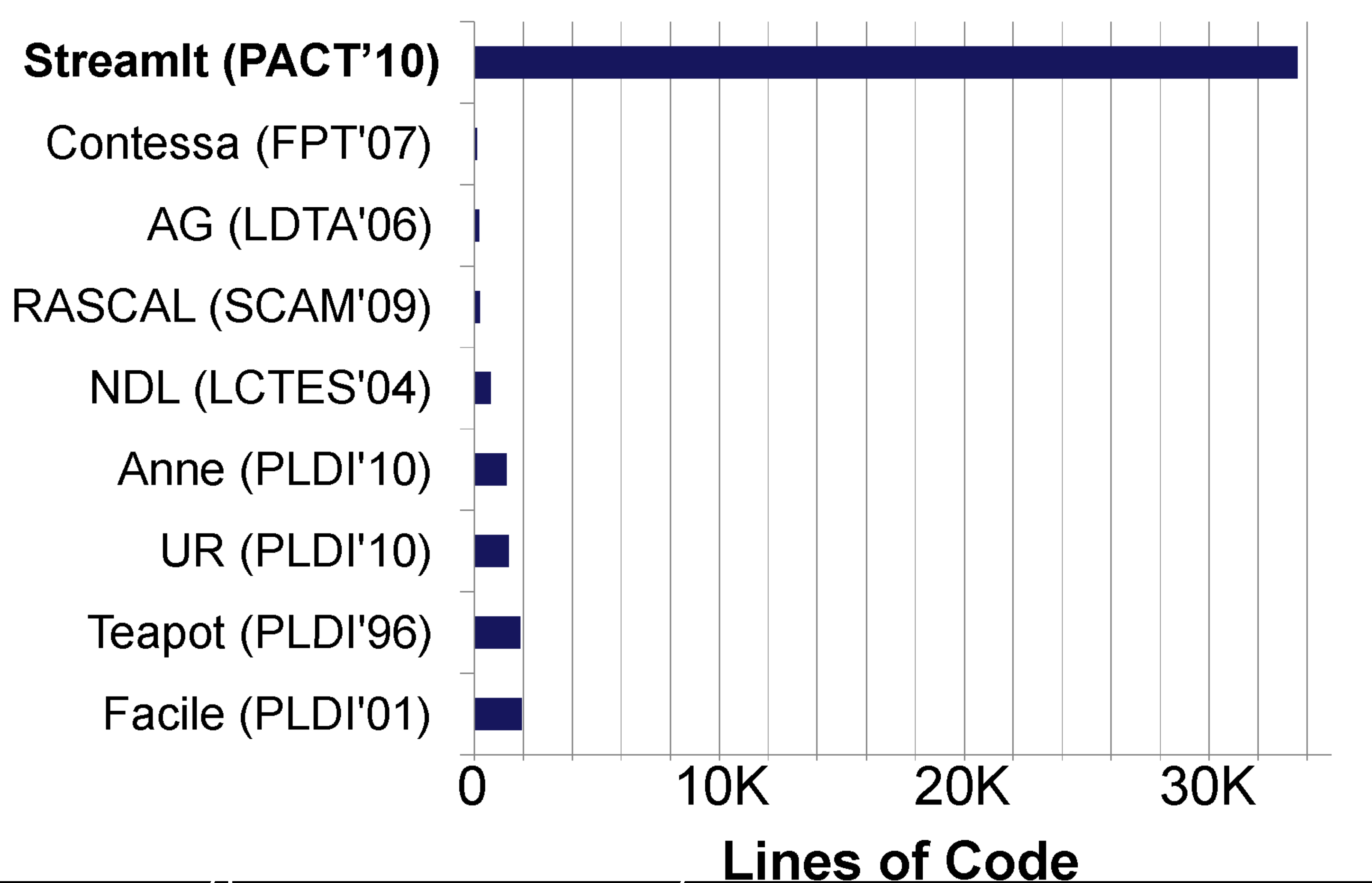
- Either…
  - We have discovered all there is to find
  - We have lost the capability to find new ones

Why it is hard to evolve a new language (feature)

- Test languages are different from production languages
  - Test language: experiment with a couple of features
  - Production language: feature complete
    - Integrate good features from multiple (test) languages
- Languages need to evolve
  - Hard to get it right the first time
  - Most user interface designs processes are set around rapid evolution with ample user feedback
- Need input from programmers to evolve
  - Need a lot of programmers to use the language
    - Different programmers think differently
  - Need programmers to use it for a long time
    - First impression is not what makes a good language
    - Measure the productivity of a trained programmer in the language

Why it is hard to evolve a new language (feature)

- Market forces work against new languages
  - Primary criteria for adoption is large number of existing users
- There is nothing in it for a programmer
  - Hard to make a long-term investment
    - The language may not last
    - At best, it'll keep changing
  - Has to deal with bugs
    - The compiler will be buggy
  - Has to deal with incomplete systems
    - Important features will be missing
    - Tools will be missing
  - More promise than reality
    - Compiler optimizable does not mean optimizations will be implemented…or works well.


StreamIt (PACT'10)
Contessa (FPT'07)
AG (LDTA'06)
RASCAL (SCAM'09)
NDL (LCTES'04)
Anne (PLDI'10)
UR (PLDI'10)
Teapot (PLDI'96)
Facile (PLDI'01)
0
10K
20K
30K
Lines of Code

Proposal: A National Center for Programming Language Evaluation

- A Virtual Center
  - Access to many professional programmers with difference skills
  - Infrastructure for scientific and unbiased evaluation
- Evaluation process akin to Drug Trials
  - Stage 1:
    - Select 20 language/feature projects
    - One week evaluation with 5 to 15 programmers
    - Write a set of small kernels
  - Stage 2:
    - Down select 4 to 5 projects
    - 3 to 6 month evaluation by 20 to 40 programmers
    - In one or two teams, develop a substantial application
  - Stage 3:
    - Down select 1 to 2 projects
    - Provide support to build/improve the tools and the compiler
    - One year effort by 50 to 100 programmers to port a real system