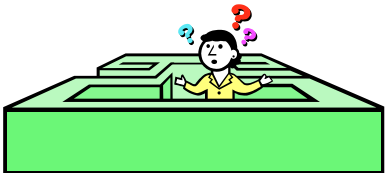
Introduction

- Parallel Programming is hard
  - Why? It's just hard
- What if there are good programming tools?
  - Profilers, Debuggers, Tester, …
  - Tools specialized parallel programming?
- State-of-the-art tools for parallel programming
  - Intel Parallel Studio
  - CriticalBlue Prism
  - VectorFabrics vfAnalyst

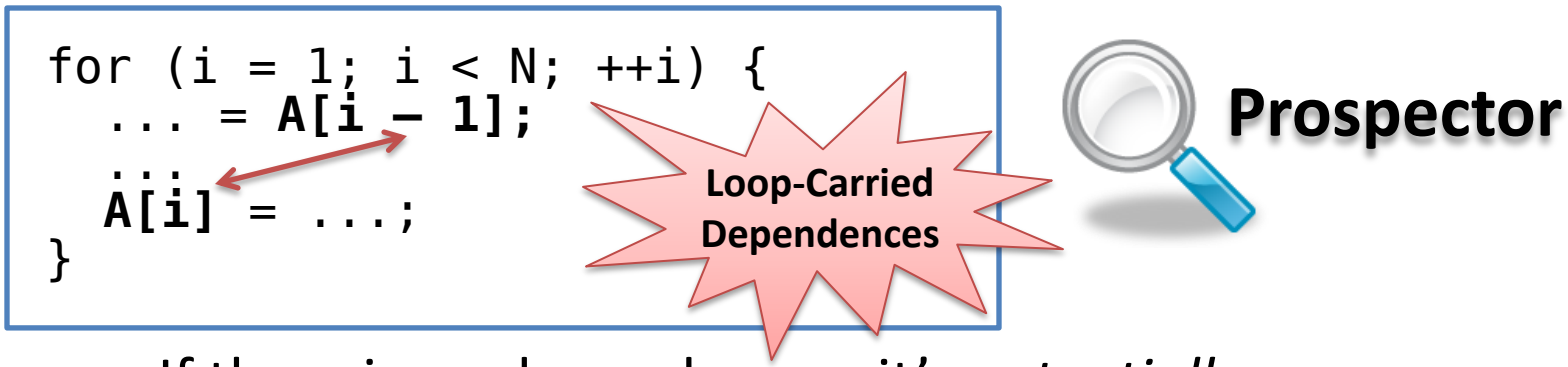
- What problems can Parallel Programming Tools help?



  - Where to parallelize?
    - Which code section do I need to look at?
  - Is this effective?
    - What would be the projected speedup?
    - What would be the optimal parallel machine?
  - How can I parallelize the code?
    - Is the code embarrassingly parallel?
    - Otherwise, must guarantee safe parallelization
    - The root cause: data dependences
    - Parallelizable code should have no dependences
      - Except parallelizable reductions

Focus of the paper

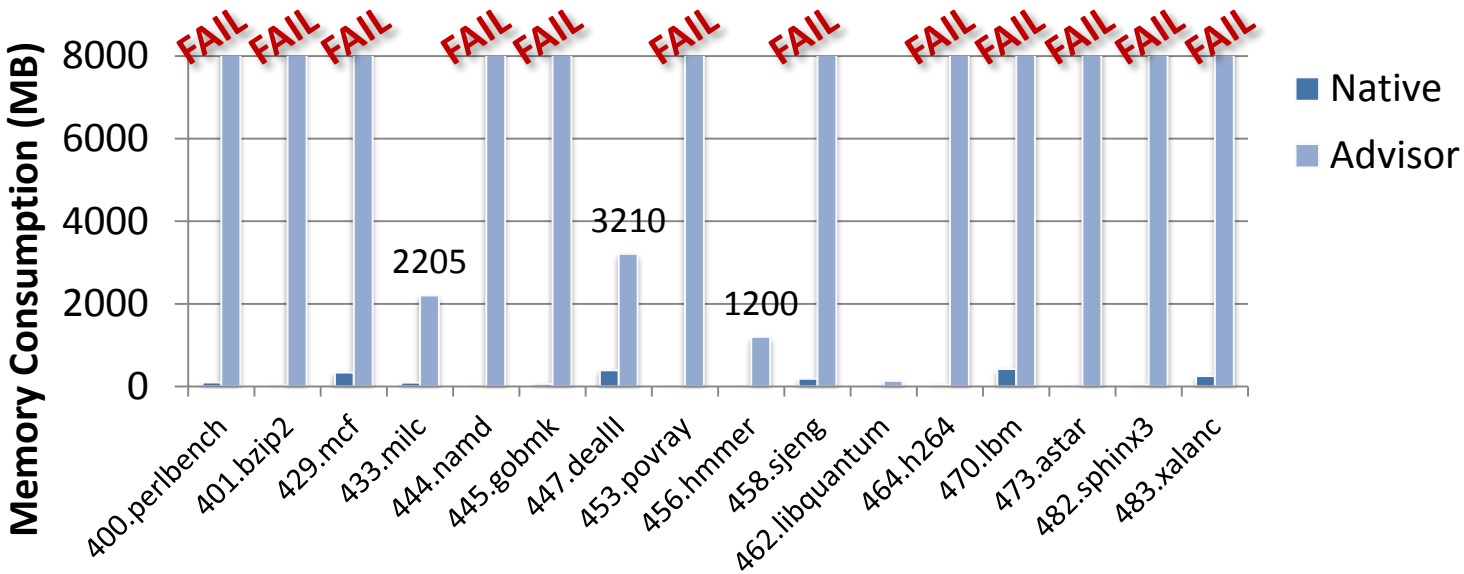
- How can we analyze data dependences?
  - Compilers can do the job, but limitations due to the pointer-to analysis problem
- An alternative: Data-Dependence Profiler
  - Dynamically analyze data dependences
- How it works?



  - If there is no dependences, it's *potentially* embarrassingly parallelizable
  - Otherwise, we report the details of discovered dependences for the parallelization

Problems

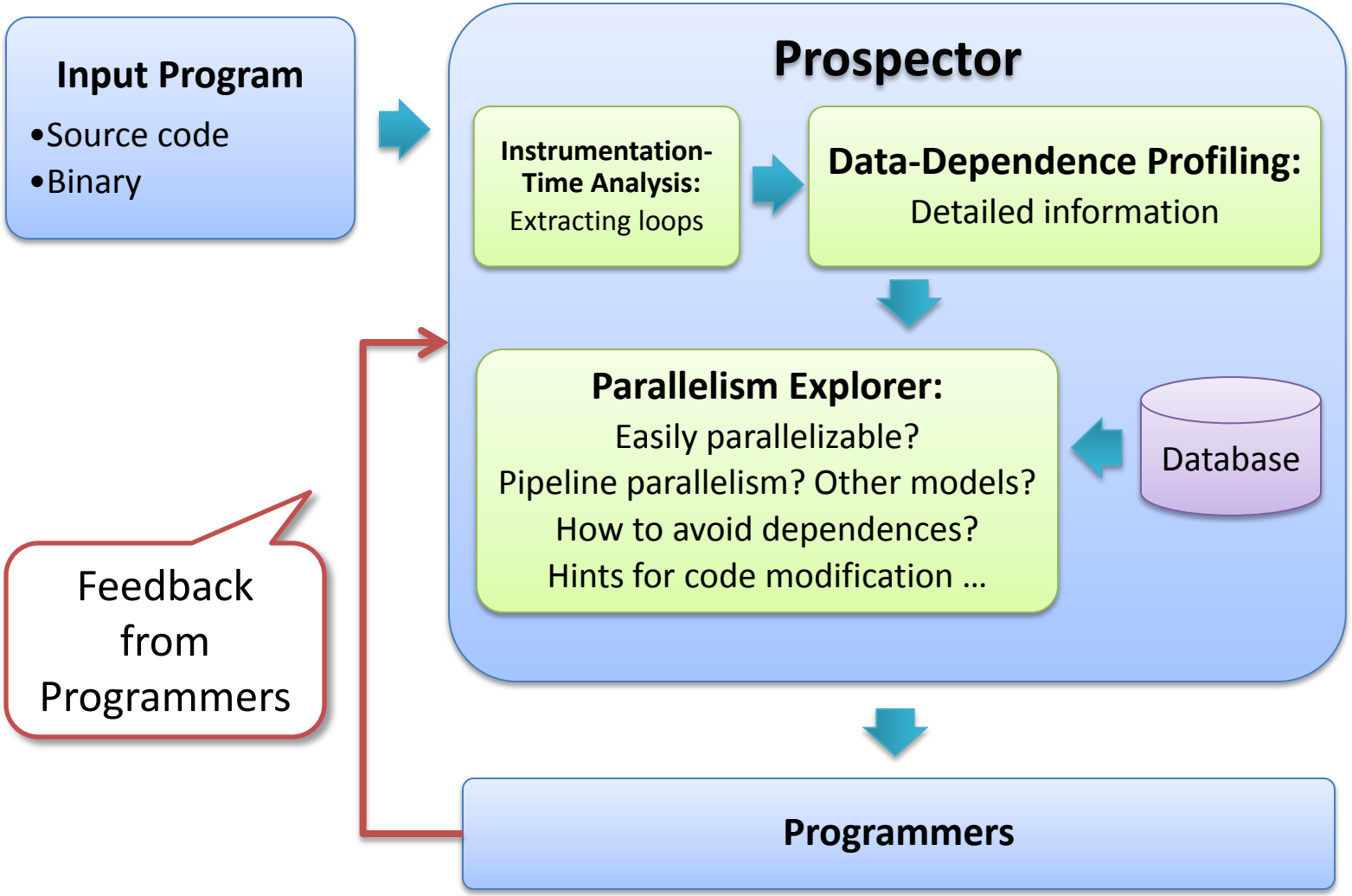
- However, current data-dependence profilers
  - Too much memory and time overheads
  - Limits features of parallel programming tools



Memory Overheads of The Dependence Profiling of Intel Parallel Advisor, SPEC 2006(train)

Overview of Prospector

- **Prospector**
  - Parallel programming assistant tool based on a dynamic data-dependence profiler
    - Finds potentially parallelizable loops
    - Provides detailed dependence information
    - Exploring hidden parallelism
      - Embarrassingly parallelizable? Yes, Prospector guides how to change the code
      - Otherwise, is there possibility to apply other types of parallelism?
  - Need a scalable and rich dependence profiler
    - Even a large and long application can be profiled with detailed information


Input Program
•Source code
•Binary
Prospector
Instrumentation-Time Analysis:
Extracting loops
Data-Dependence Profiling:
Detailed information
Parallelism Explorer:
Easily parallelizable?
Pipeline parallelism? Other models?
How to avoid dependences?
Hints for code modification …
Database
Feedback from Programmers
Programmers

Scalable Dependence Profiler

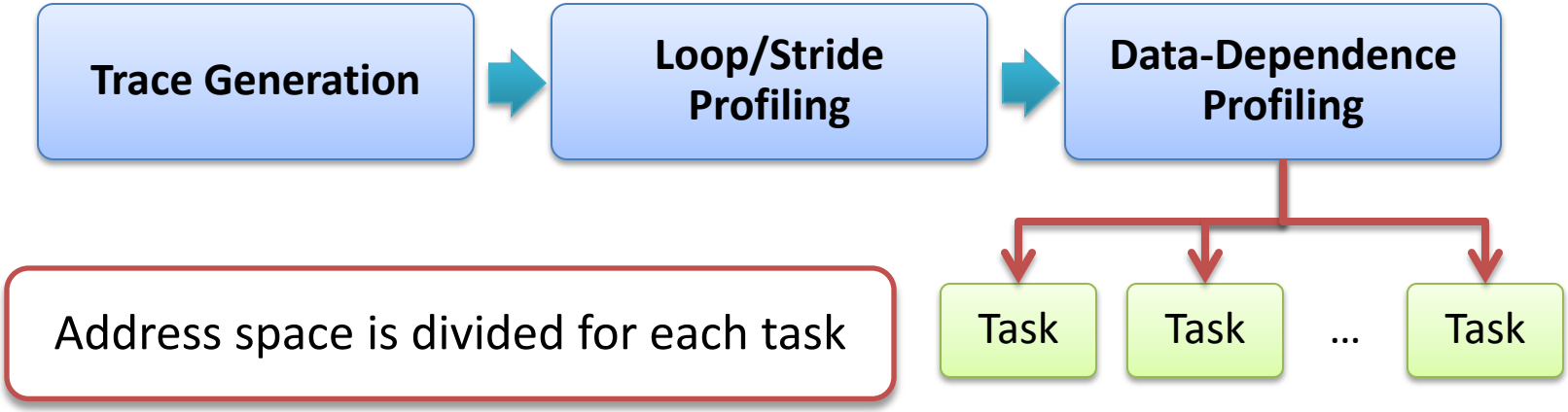
- Memory-Scalable Algorithm

  - Key observation: Find compressible patterns
  - Stride-based Dependence Checking Algorithm
  - (1) Detects strides and compresses them

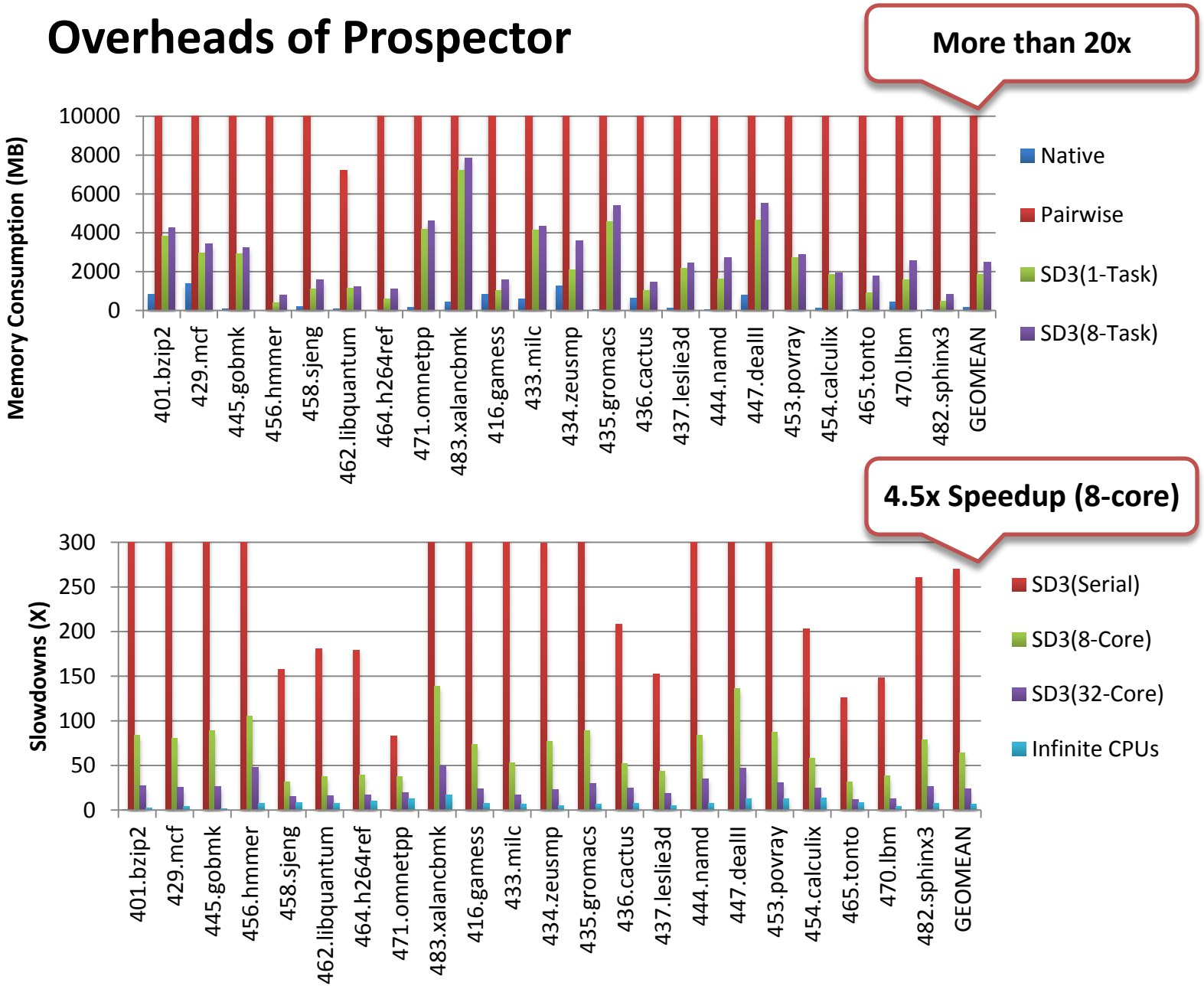
10, 14, 18, … 30 ➔ [10 + 4*i], 0 <= i <= 5

  - (2) Computes data dependences with strides
    - A new algorithm: Dynamic-GCD
  - (3) Effectively handles stride-based structures with non-stride structures

- Time-Scalable Algorithm
  - Key observation
    - Dependence profiling itself can be parallelizable 
  - A Hybrid Parallelization Model
    - Pipelined parallelization + Data-level Parallelism
  - Additional algorithms for the stride handling



Overheads of Prospector



An Illustration of Prospector

```
 1: void scan_recognize(startx, starty, endx, endy, stride)
 2: {
 3:   ...
 4:   #pragma omp for private (i,k,m,n)
 5:   for (j = starty; j < endy; j += stride)
 6:     for (i = startx; i < endx; i += stride){
 7:       ..
 8:       pass_flag = 0;
 9:       match();
10:       if (pass_flag == 1) {
11:         if (set_high[tid][0] == TRUE) {
12:           highx[tid][0] = i, highy[tid][0] = j;
13:           set_high[tid][0] = FALSE;
14:         }
15:         if (set_high[tid][1] == TRUE) {
16:           ...
18:     }  // End of for-i
...
30: void match()
31: {
32:   reset_nodes();
34:   while (!matched) {
35:     ...
48:     int match_cnfd = simtest2();
41:     if ((match_cnfd) > rho) {
43:        pass_flag = 1;
44:       if (match_cnfd > highest_confidence[tid][winner]){
45:         highest_confidence[tid][winner] = match_cnfd;
46:         set_high[tid][winner] = TRUE;
47:       }
48:     ...
```

```
70: void reset_nodes()
71: {
72:   for (i=0;i<numf1s;i++) {
73:     f1_layer[tid][i].W = 0.0;
74:     Y[tid][i].y = 0.0;
```

Hot Loop

Parallelizable after Reduction

Loop-carried WAW: Privatization

Loop-carried RAW:
Parallel Reduction MAX

Conclusion

- We claim the Dynamic Dependence Profiler
  - Will be a basis tool that assistants parallel programming
- We present **Prospector**
  - Parallelism extraction and parallel programming guiding tool
  - Based on a scalable data-dependence profiler
  - Predict parallelizable loops if no dependences
  - Guides code change to avoid dependences

Future Work

- What about hard-to-parallelize loops?
  - Can Prospector guide parallelization for loops which have true dependences?
    - Ideally, we want to provide hints such as "insert locks or use transactional memory at this point to parallelize the loop"
  - Can Prospector give advice on parallelization methodologies?
    - Use multicores for this loop with OpenMP or TBB, but try to GPGPU or SIMD for that loop