POSH:
A Profiler-Enhanced TLS Compiler that Leverages Program Structure

Wei Liu, James Tuck, Luis Ceze, Karin Strauss, and Josep Torrellas

University of Illinois at Urbana-Champaign

http://iacoma.cs.uiuc.edu

Jose Renau

University of California at Santa Cruz
http://masc.soe.ucsc.edu

This work was funded by DARPA-IBM under PERCS.

Introduction

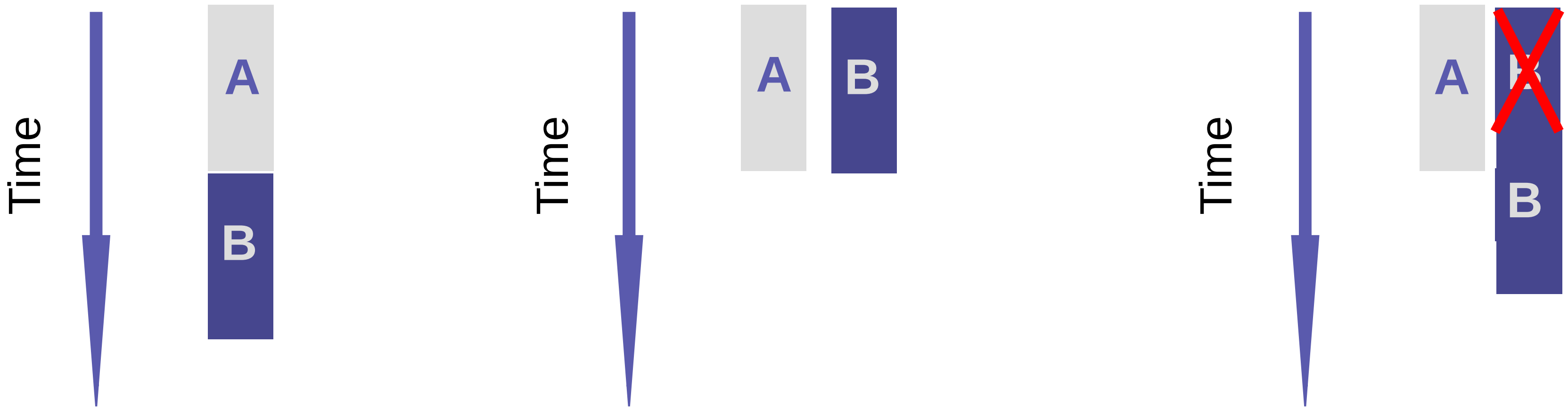
- Chip multiprocessors (CMPs) have arrived
  - Pentium D
  - Opteron dual core
  - Power5
  - Niagara
- How do we speedup hard-to-parallelize single-threaded applications on CMPs?

➡ Thread-Level Speculation

Thread-Level Speculation (TLS)

- TLS Hardware
  - Tracks data accesses at run-time
  - Detects dependence violations
  - Squashes and restarts tasks

Sequential **TLS (no dep violations)** **TLS (dep violations)**



Motivation

- Most TLS work consists of proposing architectural variations
  - We need to turn our focus to thread extraction
- Automated TLS compilers are key to TLS acceptance

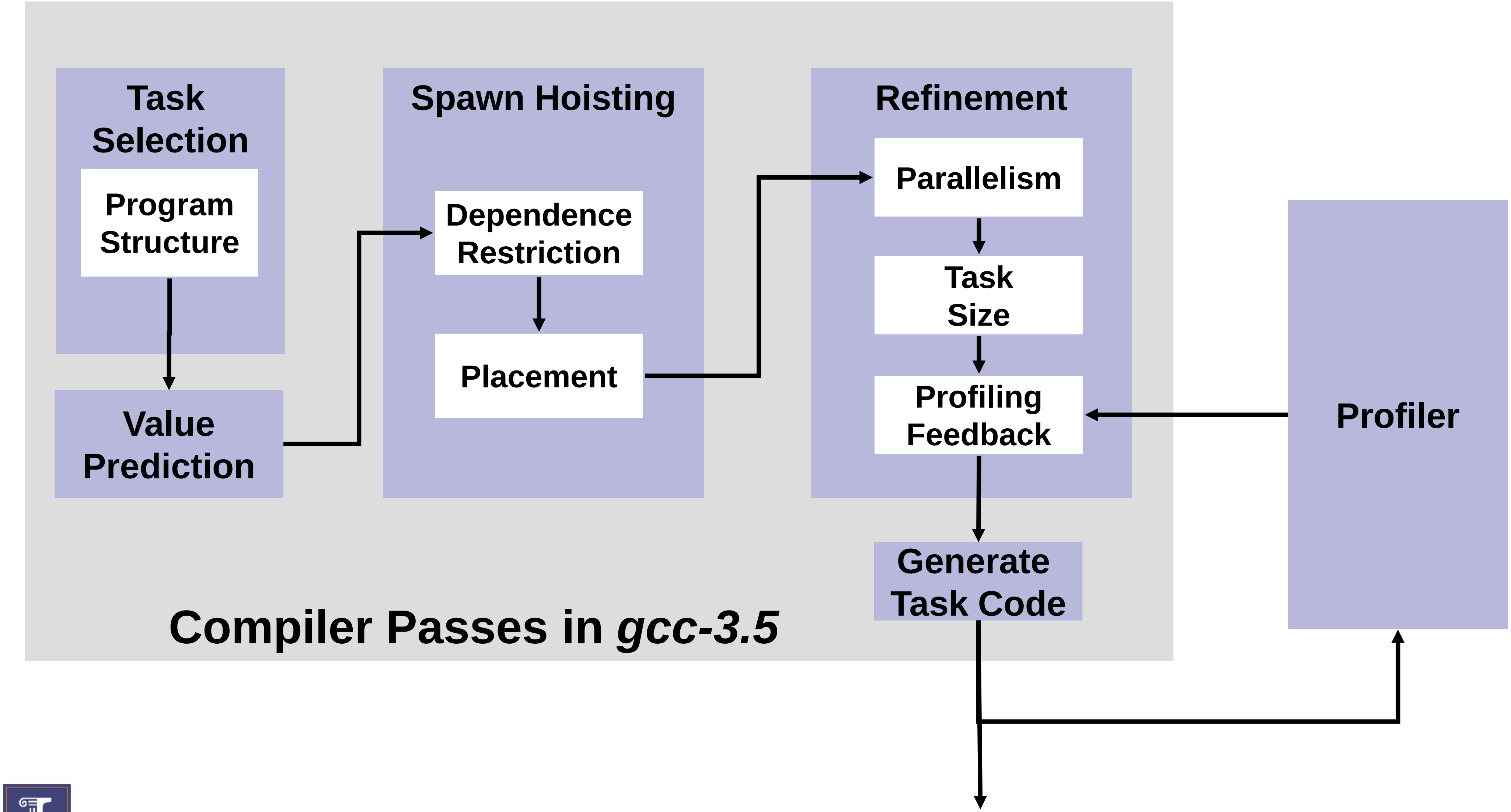
Main Contributions

- POSH is a fully automated TLS compiler for SPECint class applications
    - Simple
        - Leverages code structure (loops, subroutine continuations) for tasks
    - Effective
        - Average speedup for SPECint applications of 1.28 over sequential on a 4-core CMP
    - Leverages both parallelism and data prefetching
- We evaluated the impact of several key decisions:
    - Task structures
    - Use of a profiler
    - Value prediction

Outline

- Overview of POSH
- Compiler
- Profiler
- Methodology
- Evaluation

Flowchart of the POSH Framework



CMP Hardware for TLS

- All data dependences are carried through memory
  - No special hardware for register communication
- Support task *spawn* and *commit* instructions

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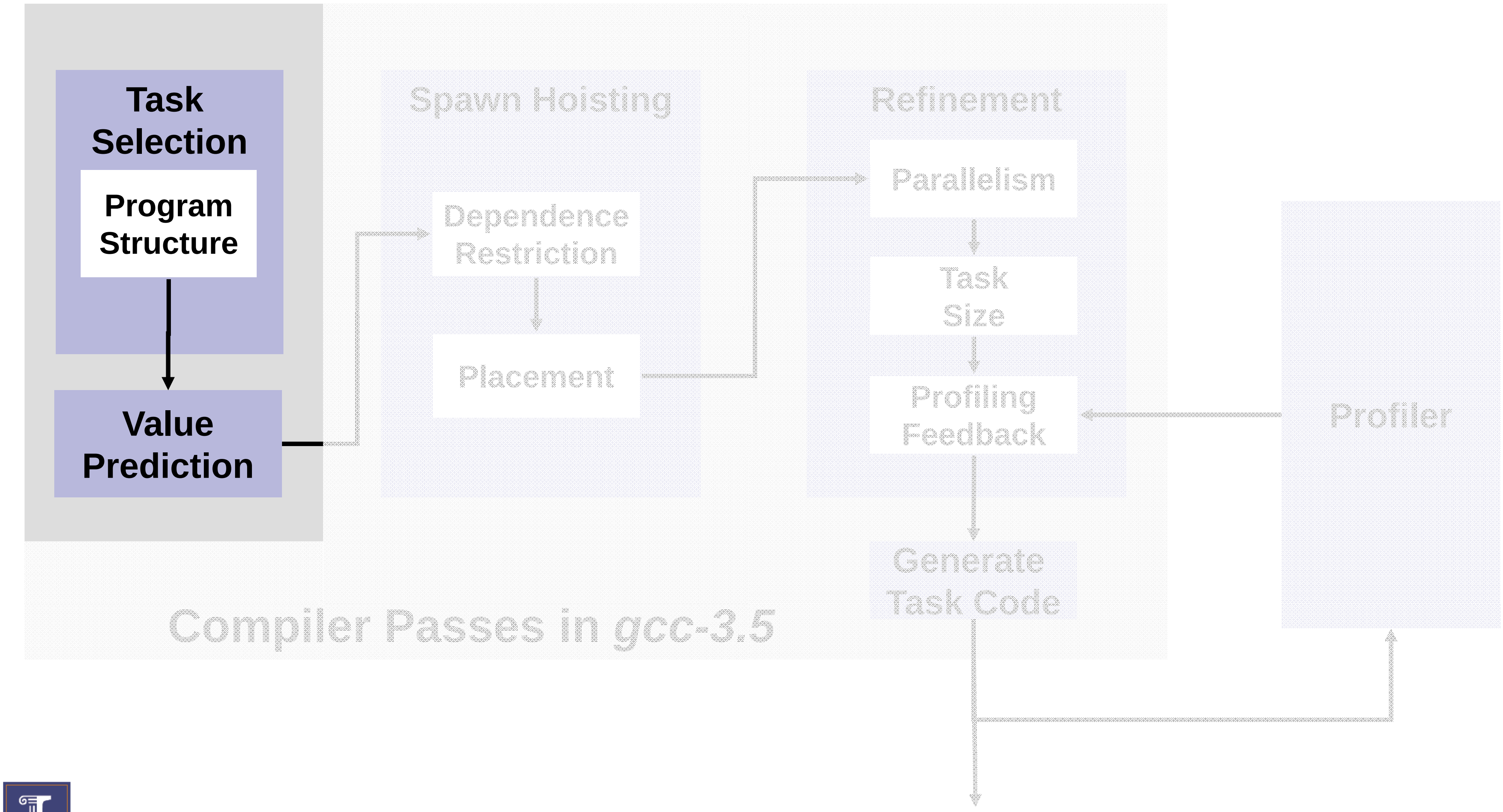
Task Selection



Task Selection

Program Structure

Value Prediction

Spawn Hoisting

Dependence Restriction

Placement

Refinement

Parallelism

Task Size

Profiling Feedback

Generate Task Code

Profiler

Compiler Passes in *gcc-3.5*

Task Selection

- Break the sequential program into tasks
- Select tasks without regard for nesting
- Select the following structures
  - Subroutine continuations
    - Restrict based on return value and size
  - Loops
    - Consider all loops found using strongly connected components

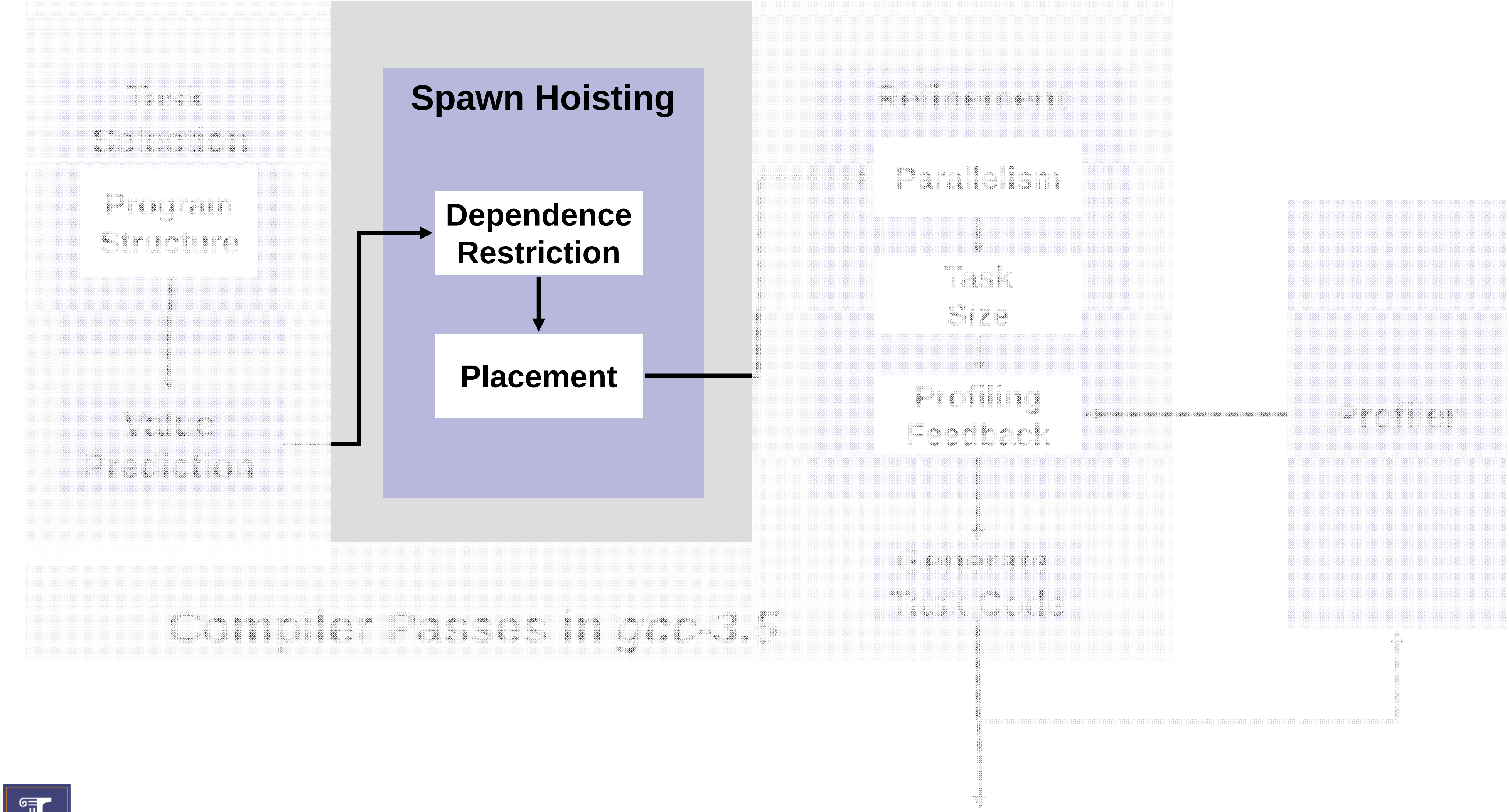
A

B

C

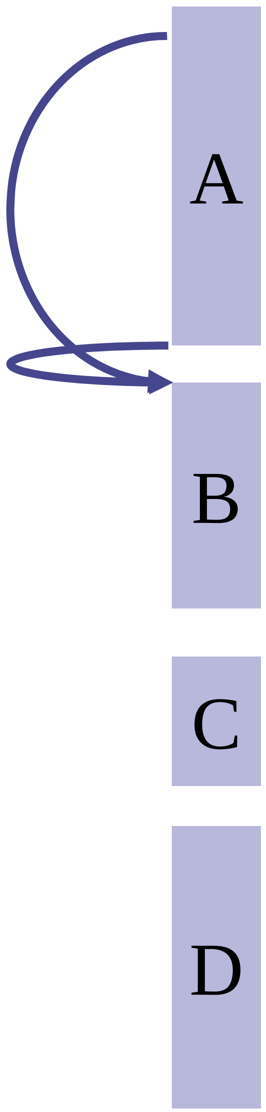
D

Spawn Hoisting

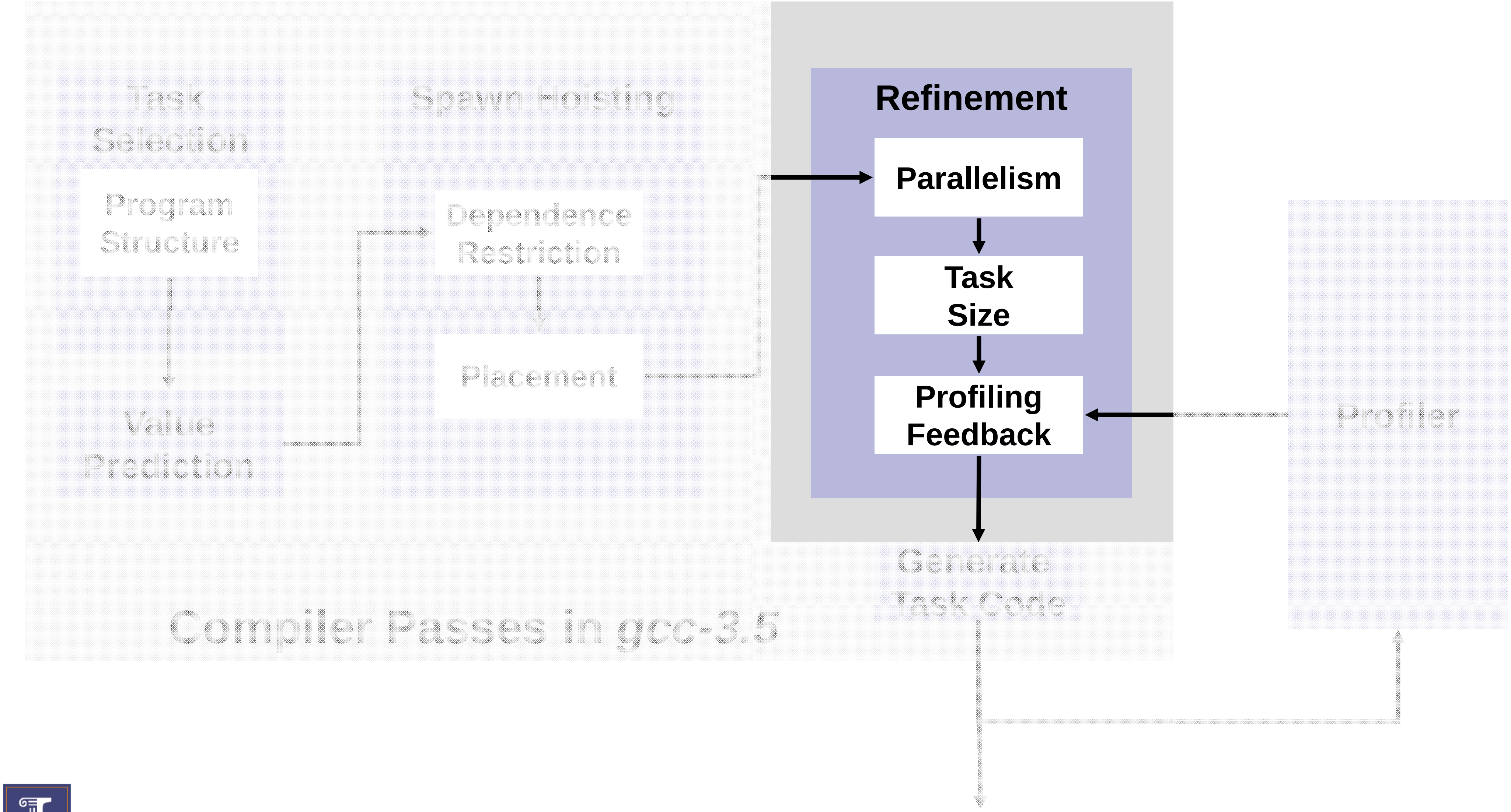


Spawn Hoisting

- The spawn instruction is *hoisted* relative to the beginning of a task
- Goal is to provide parallelism and prefetching
- Restrictions on hoisting
  - Spawn after the definition of variables used in the task
  - Spawn must be control safe
    - We avoid complications of control misspeculation



Refinement


Task Selection
Program Structure
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Spawn Hoisting
Dependence Restriction
Placement
Refinement
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Task Size
Profiling Feedback
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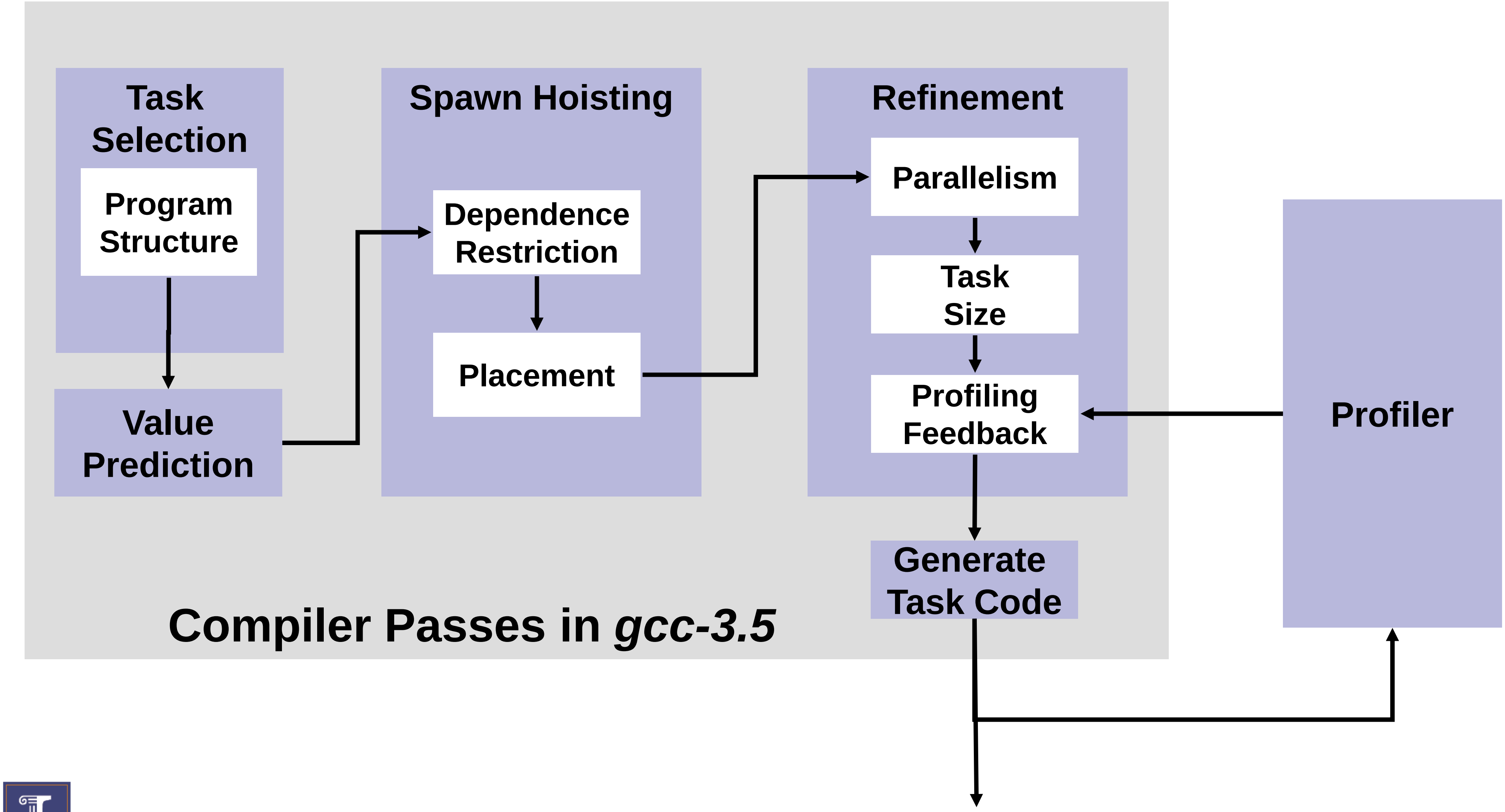
Generate Task Code
Compiler Passes in *gcc-3.5*

Static Task Refinement

- Static refinement eliminates tasks:
  - Determined to be very small
  - Offering little parallelism due to small hoist distance

- Feedback by profiling with small data set size:
  - List of most beneficial tasks

Generate Code For Tasks



Task Selection

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Generate Task Code

Profiler

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An Example of the Compiler at Work

- First select the task
    - Task label, commit
- Identify spawn location
- Pass dependences through memory

```
       int i=0;

       …

Loop:
       if( i > 99 )
         goto Lend;

       <LOOP BODY>

       i = i + 1;

       goto Loop;
Lend:
```

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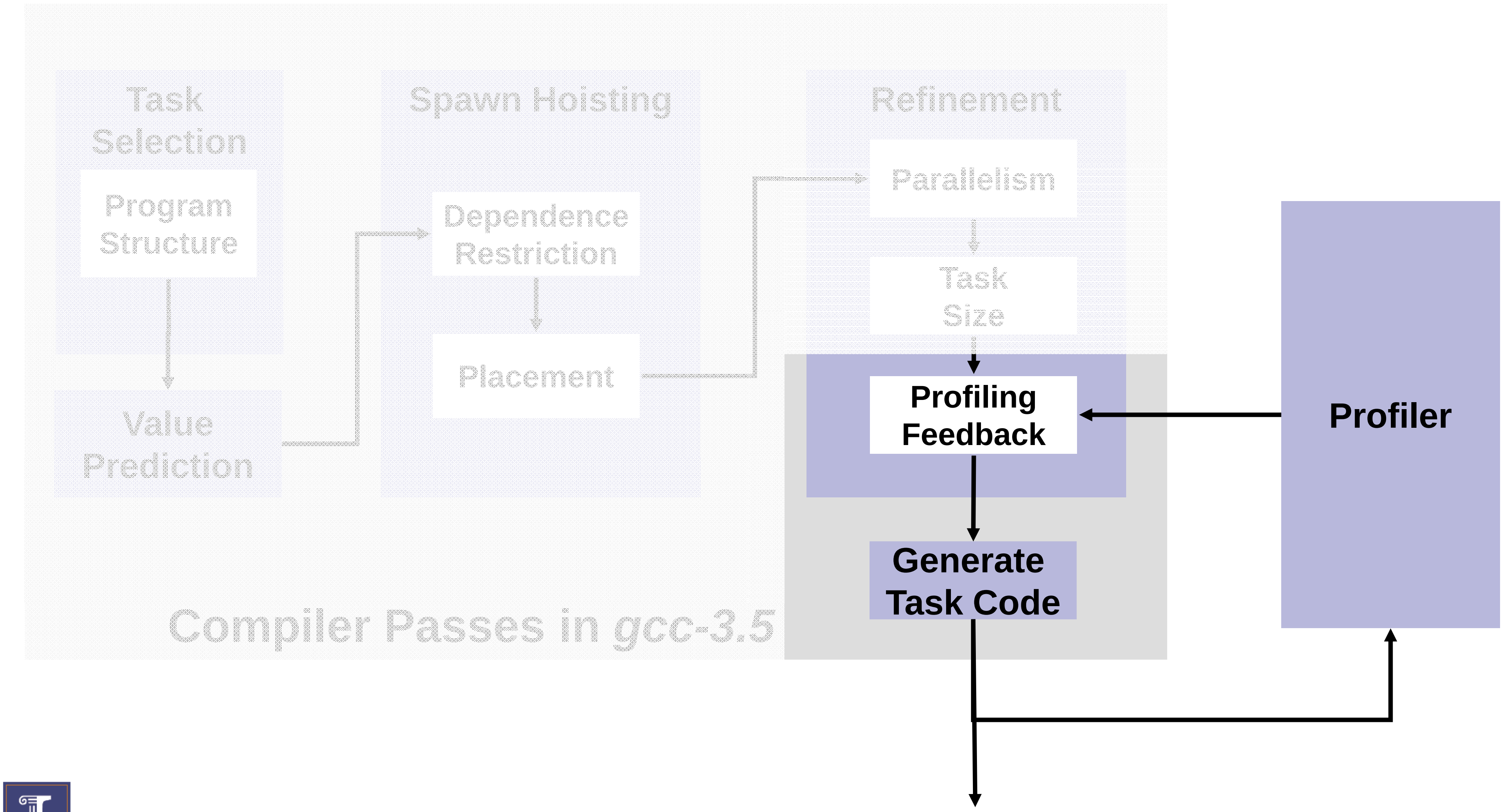
The POSH Profiler

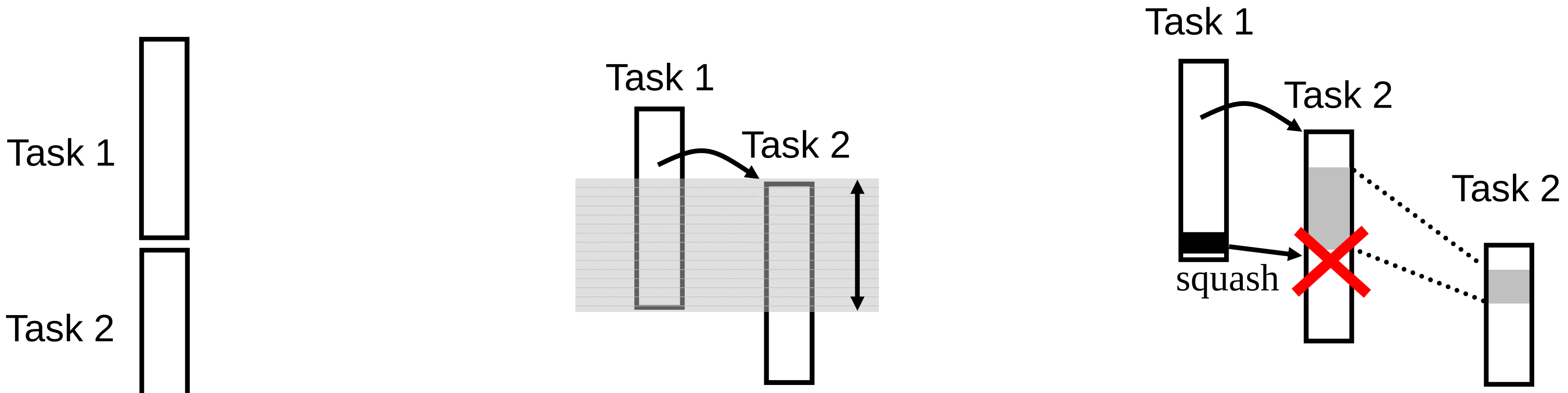


Profiler Details

- Runs a TLS binary with all tasks selected by the compiler
  - Uses train input set for SPECint
- Executes the TLS binary *sequentially*
  - No TLS architectural support assumed for generality
- Provides a simple L2 cache model to estimate misses
- Not tied to a fixed number of processors

The Profiler’s Goals

- Preserves parallelism
  - Keeps tasks with good overlap
- Rewards prefetching
  - Keeps tasks that prefetch for themselves



Benefit = *Overlap* + *Prefetching*

Profiler Phases

- Eliminate tasks using dynamic information
  - Small dynamic task size
    - BUT, if a small task spawns a successor, treat it with care
  - Small or large spawn hoist distance
    - If too small, then no overlap
    - If too large, then potentially too many data dependences
  - Too many squashes per invocation
    - Apply a *prefetching correction* to this rule
    - If *Benefit* is high, keep task regardless of squash rate

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Methodology

- Simulated Architecture
  - 4-core chip multiprocessor
  - 4 GHz, 3-issue core
  - Detailed cache hierarchy model
    - Per core private 16k L1
    - 1MB Shared L2
    - Speculative data kept in the L1
    - Cache coherence protocol aware of versions
  - Main memory latency of 500 cycles
  - 12 cycle spawn, 20 cycle squash overhead
- Full program simulation (not just loops)

Applications

- Evaluated SPECint 2000
    - Except *gcc*, *perlbmk*, *eon*
- First, apply SGI's source-to-source optimizer (copt)
- Non-TLS binary compiled with gcc-3.5 using –O2
- TLS binary compiled with POSH

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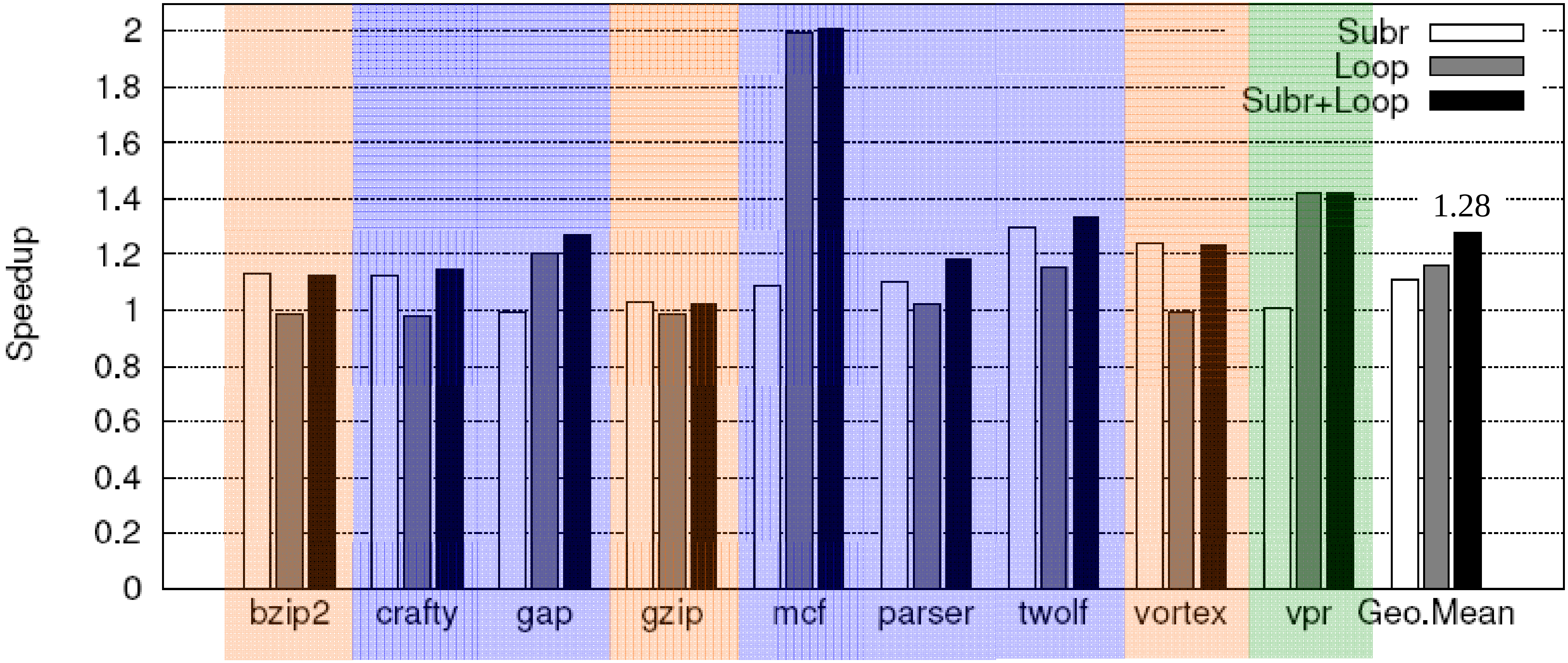
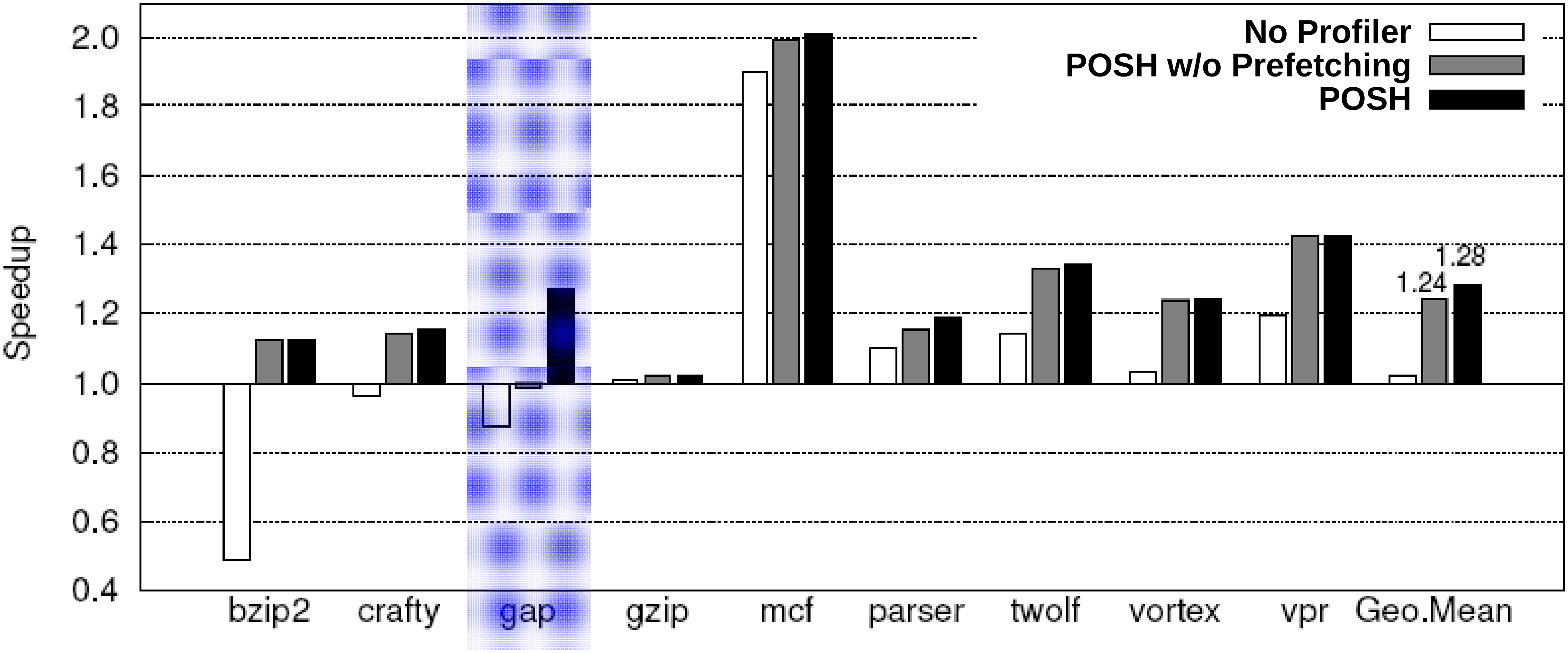
TLS Speedup Over Sequential Execution



Achieve an average speedup of 1.28 on SPECints!

Using both forms of tasks is simple and effective

Profiler Effectiveness



Targeting prefetching improves performance

Conclusions

- A TLS compiler utilizing program structure and a profiler delivers good speedups
    - 1.28 average speedup for SPECints
- For better performance, consider both parallelism and prefetching
- We evaluated the impact of several important design decisions
    - Employ both subroutine continuations and loops for best performance
    - Usefulness of the profiler
    - Value Prediction

Thank You

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Backup
Slides

Selection and Hoisting Example

```
       int i=0;

       …

Loop:
       if( i > 99 )
         goto Lend;

       <LOOP BODY>



       i = i + 1;

       goto Loop;
Lend:
```

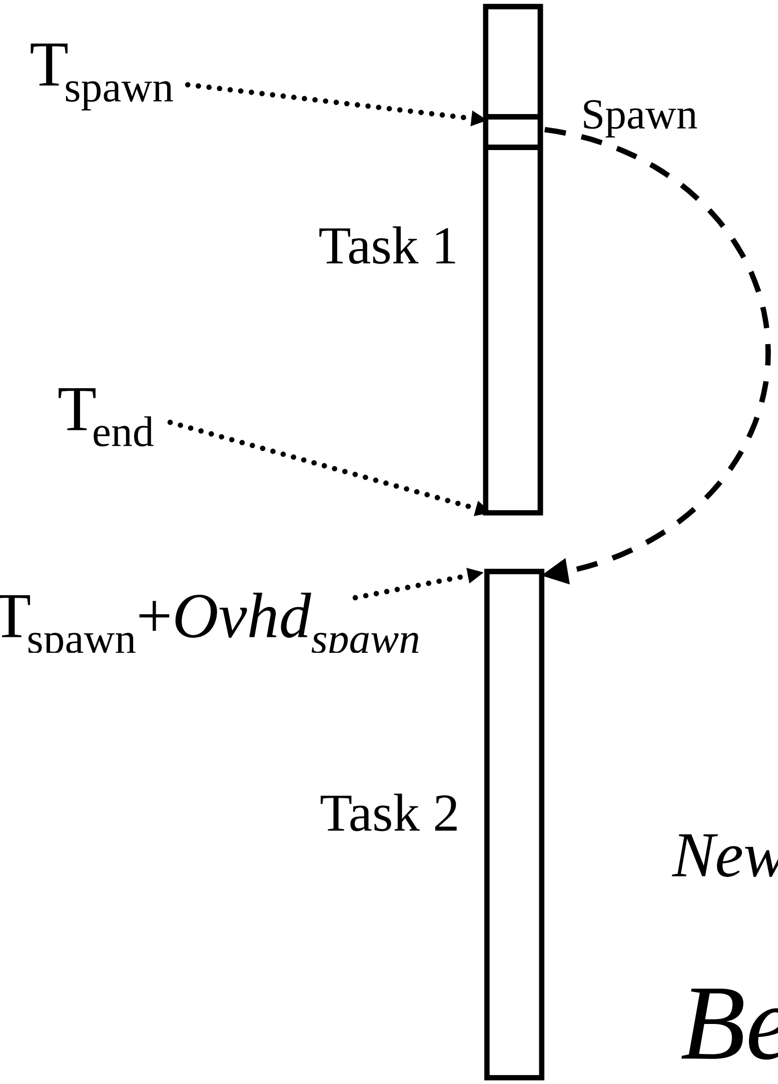
```
int x=0;

…


x = f(x);





do_something(x);
```

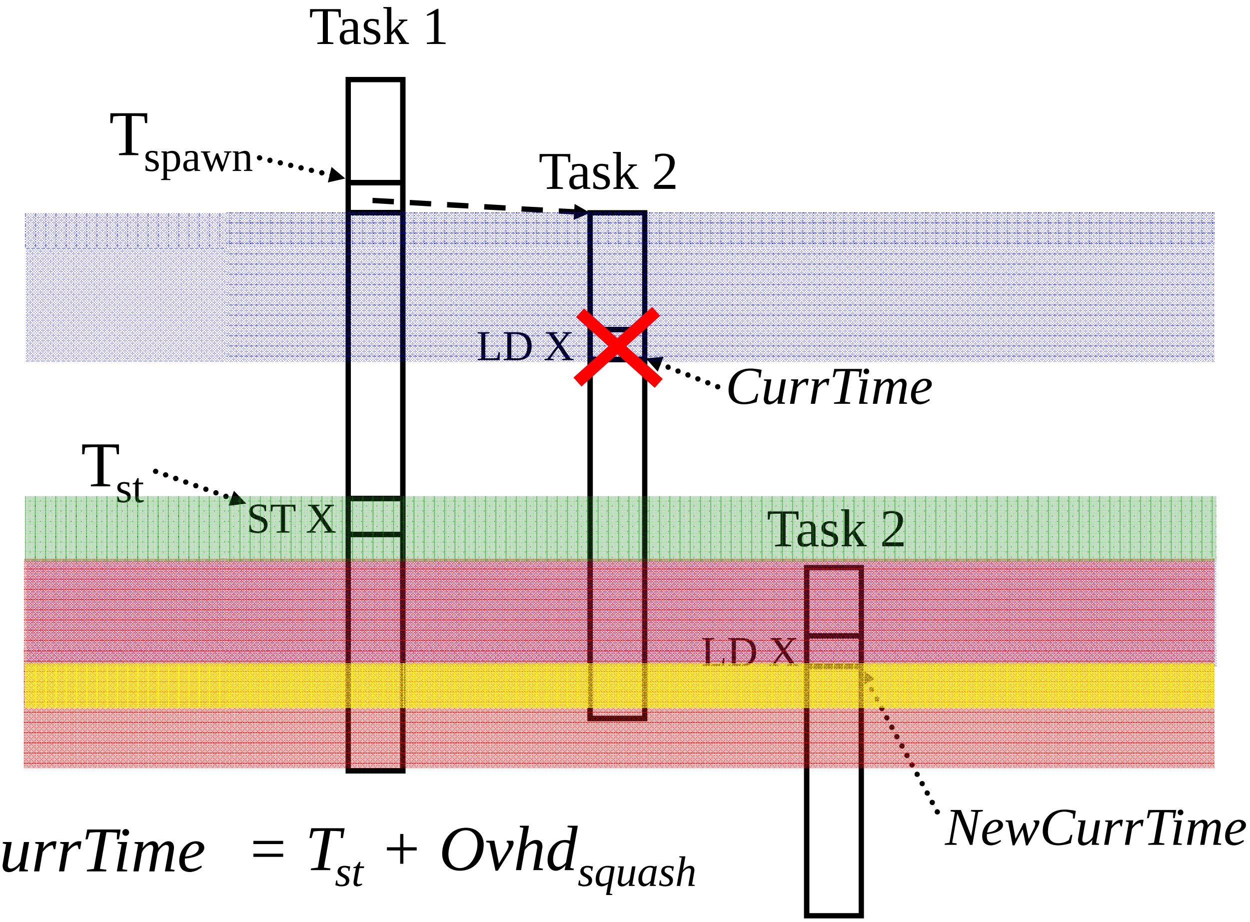
What is a “Task” in POSH?

- From the perspective of POSH:
  - *Begin point*
  - *Spawn point*
- Runtime perspective
  - Dynamic execution between *begin points*

```
 spawn Task1;
 Do_some_work();
Task1:

 while( i < 1000 ) {
  spawn Task2;
  …

  …

Task2:
  i++;
 }
 Do_some_more_work();
```

Estimating Task Performance and Benefit





$$NewCurrTime = T_{st} + Ovhd_{squash} + CurrTime - T_{spawn} - Ovhd_{spawn}$$

$$Benefit = Overlap + Prefetch - MissOvhd$$

Characterization of Profiling

App.	#Tasks Before	# Elim. For Size	# Elim. For Hoist	# Elim. For Squashing	#Saved for Pref.	# Tasks After
gap	36	0	13	11	**7**	12
mcf	17	2	6	4	1	5
parser	464	47	78	158	6	181
vpr	21	0	0	18	0	**3**
Average	**139.7**	14.8	33.7	**55.8**	2.1	**35.4**

Thread-Level Speculation (TLS)

Sequential ⇨

```
for(i=0;i<n;i++) {
  X[Y[i]] = X[Z[i]]...
}
```

- With TLS:
  - Assume no dependences
  - Run in parallel
  - Auto detect violations

TLS Task A ⇨

```
for(i=0;i<n/2;i++) {
  X[Y[i]] = X[Z[i]]...
}
```

TLS Task B ⇨

```
for(i=n/2;i<n;i++) {
  X[Y[i]] = X[Z[i]]...
}
```