Evaluating the capabilities of the Xeon Phi platform in the context of software-only, thread-level speculation

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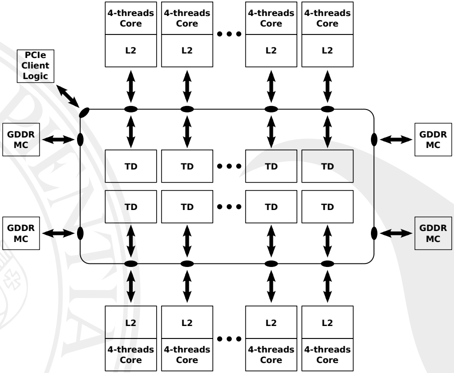
Summary

In this talk, we will. . .

- Briefly review the capabilities of the Xeon Phi coprocessor.
- Present a not-so-common case study: Thread-Level Speculation (TLS).
- Describe our software-based TLS solution (ATLaS).
- Show what happens when running ATLaS in the Xeon Phi.
- Enumerate conclusions and discuss future work.

Intel Xeon Phi in a nutshell

- Coprocessor launched in 2012.
- Can run an OS by itself, but still needs a host computer.
- Composed of up to 61 four-way SMT cores.
- Interconnected by a high-speed bidirectional ring.



Intel Xeon Phi: Pros and cons

- Pros:
  - It acts as a shared-memory multiprocessor.
  - Standard parallel programming models (OpenMP, MPI, OpenCL) can be used.
  - Uses Intel 64-bits architecture with 512-bits-wide FP SIMD instructions.
  - Excellent memory bandwidth (240 GB/s vs. 51.2 GB/s of our AMD Opteron SM system).
- Cons:
  - In-order execution.
  - Modest clock speed.
  - If SIMD instructions are not heavily used, no so many computational units to overcome these limitations.

How to use the Intel Xeon Phi

Two ways:

- **Native execution** Once an OS is installed, log into the system, compile and run the parallel application natively.
- **Offloading from the host** Compile the code in the host system, using software extensions in the source code to offload tasks from the host to the Xeon Phi.
  - OpenMP example: `#pragma offload target{mic}`
  - Variables exchange should be declared explicitly, with `in()`, `out()` or `inout()` clauses.

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  - OpenMP example: `#pragma offload target{mic}`
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Our goal: to evaluate the Xeon Phi capabilities when running a software-based Thread-Level Speculation (TLS) system.

Thread-Level Speculation (TLS)

Parallelization with OpenMP

```
for (i=0; i<MAX; i++) {
   b = func(i);
   v[i] = b * a[i];
}
```

(a) Original loop

```
#pragma omp parallel for \
 private (i,b) shared (a,v)
for (i=0; i<MAX; i++) {
   b = func(i);
   v[i] = b * a[i];
}
```

(b) Loop parallelized with OpenMP directives

Thread-Level Speculation (TLS)

What happens if the loop may present dependence violations?

```
for (i=0; i<MAX; i++) {
   b = func(i);
   if (b==k)
      v[i] = v[i-b];
   else
      v[i] = b * a[i];
}
```

Loop not safely parallelizable

Thread-Level Speculation (TLS)

- Aims to execute in parallel fragments of code without requiring compile-time analysis.
- Iterations are divided in blocks and optimistically executed in parallel, hoping that no dependence violations will appear.
- In software-based TLS, original code is augmented with function calls that monitors the parallel execution at runtime.
- *Offending* threads (that have consumed a value before being produced by a predecessor thread) are dynamically stopped and re-started with correct values.
- Consistency with sequential semantics is ensured by the runtime system.
- Suitable for shared-memory systems.

The ATLaS framework

- ATLaS[1] is a software-based, TLS framework that extends OpenMP functionalities to allow the parallelization of loops that may present dependences between iterations.
- ATLaS allow the speculative management of scalar variables and data structures, and can handle accesses through pointer arithmetic.
- Documentation and software download:

atlas.infor.uva.es

[1] **An OpenMP Extension that Supports Thread-Level Speculation**, Aldea, Estebanez, Llanos, Gonzalez-Escribano, IEEE TPDS, 2015.

Speculative parallelization using ATLaS

(a) Loop not parallelizable safely	(b) Loop parallelizable using ATLaS

<pre>for (i=0; i<MAX; i++) {
   b = func(i);
   if (b==k)
      v[i] = v[i-b];
   else
      v[i] = b * a[i];
}</pre>
	<pre>#pragma omp parallel for \
	 private (i,b) shared (a,k) \
	 speculative(v)
	for (i=0; i<MAX; i++) {
	   b = func(i);
	   if (b==k)
	      v[i] = v[i-b];
	   else
	      v[i] = b * a[i];
	}</pre>

The ATLaS compile phase

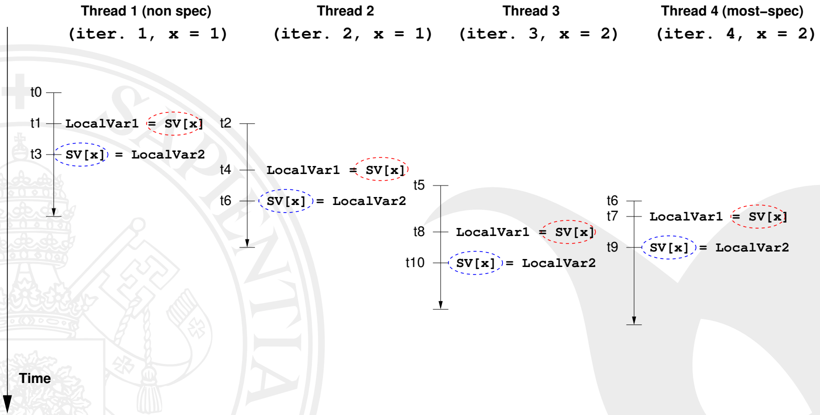
- At compile time, the ATLaS GCC compiler plug-in replaces accesses to speculative variables with calls to speculative functions.
- Example: Let a, b and c be three variables labeled as speculative:

Original code	**Augmented code**

`#pragma omp...`
` speculative (a,b,c)`
`for (...) {`
`   a = 9;`
`   b = 11.7*2;`
`   lhs = c;`
`}`
	`#pragma omp...`
	
	`for (...) {`
	`   specstore(&a,sizeof(a),9);`
	`   specstore(&b,sizeof(b),23.4);`
	`   specload(&c,sizeof(c),&lhs);`
	`}`

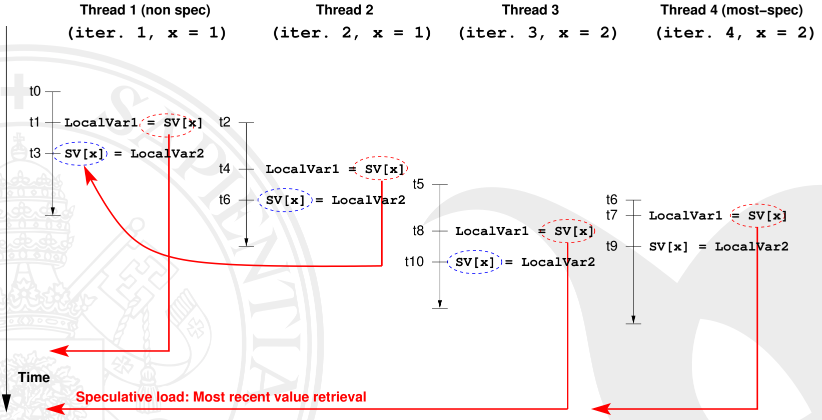
TLS: An example

- Suppose that the SV vector was labeled as speculative.
- Index x is not known at compile time.



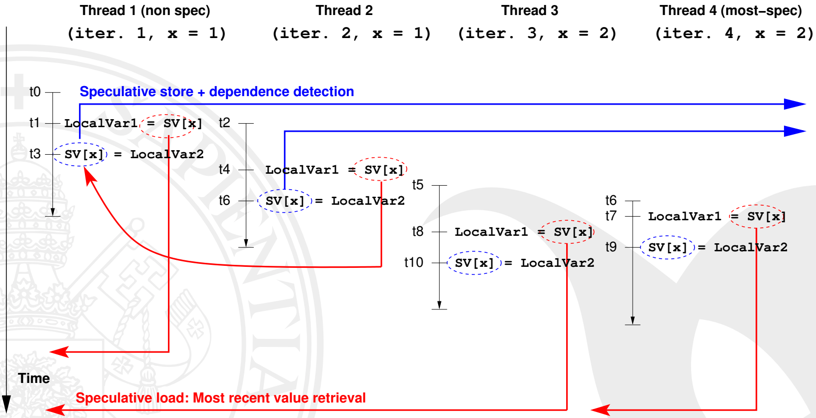
TLS: Speculative loads

- Suppose that the `SV` vector was labeled as `speculative`.
- Index `x` is not known at compile time.



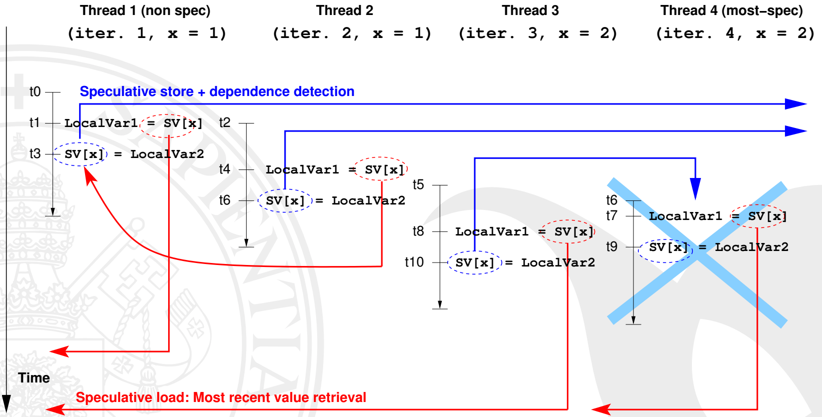
TLS: Speculative stores (no violations)

- Suppose that the SV vector was labeled as speculative.
- Index x is not known at compile time.



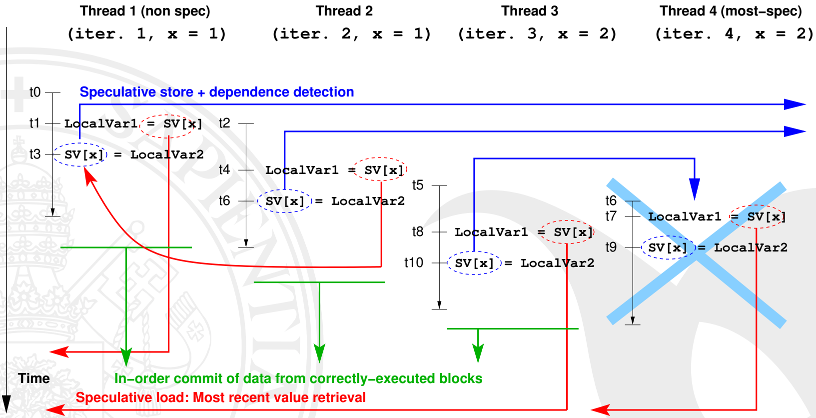
TLS: Speculative stores (squash)

- Suppose that the `SV` vector was labeled as `speculative`.
- Index `x` is not known at compile time.

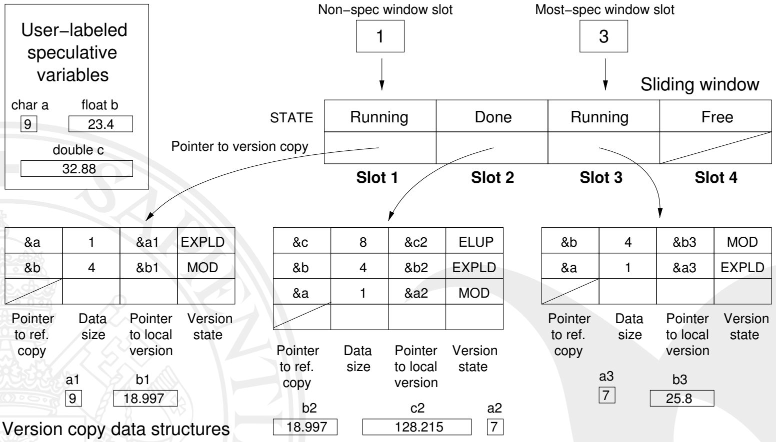


TLS: Commitment of shared variables

- Suppose that the SV vector was labeled as speculative.
- Index x is not known at compile time.



The ATLaS runtime system



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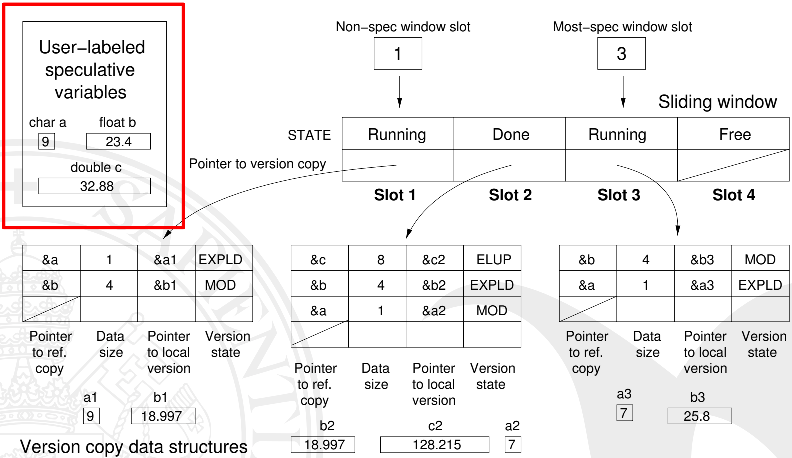

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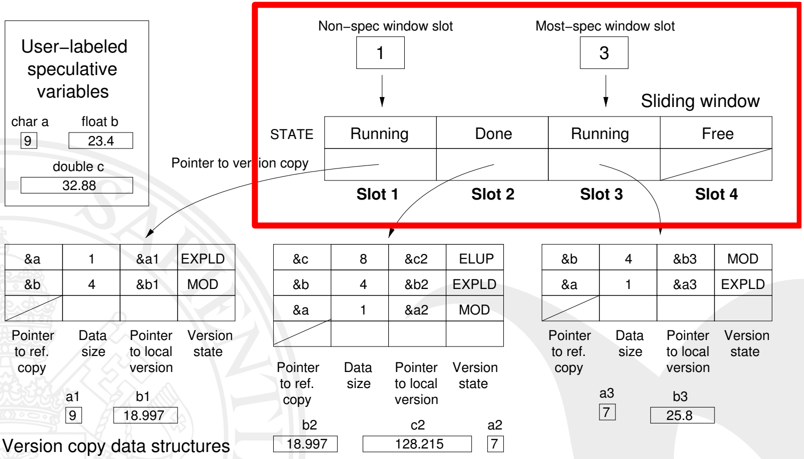

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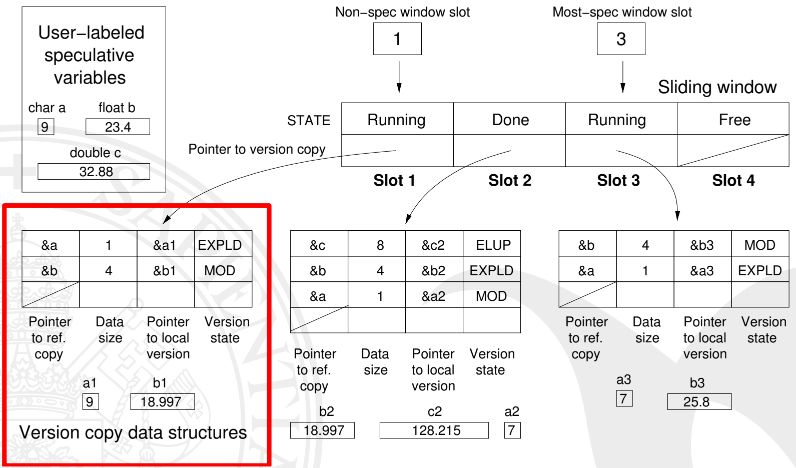
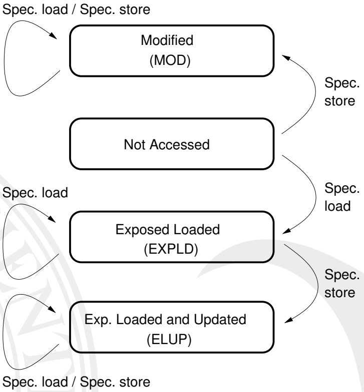


ATLaS transition state diagram

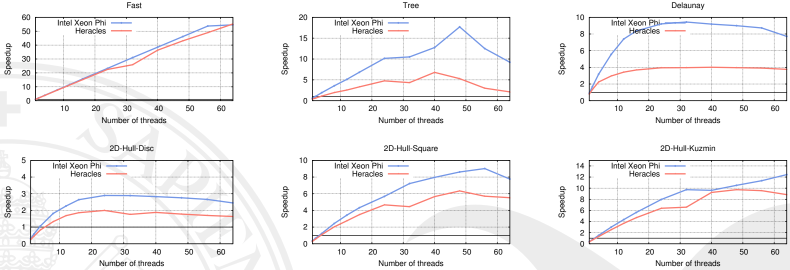


Evaluating ATLaS running on Xeon Phi

Benchmarks considered

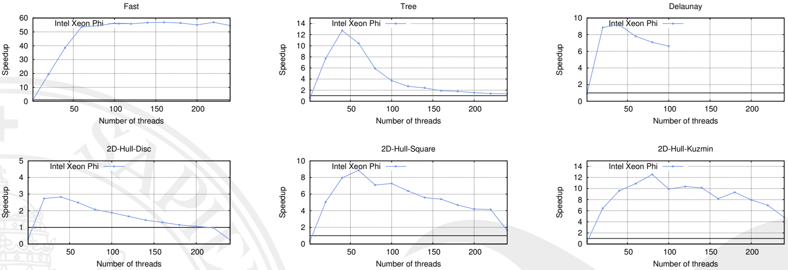
- Three benchmarks representative of real-world problems:
  - 2D-DT (Delaunay Triangulation)
  - 2D-Hull (Convex Hull) with three different input sets.
  - TREE
- They present a significant squash-and-restart rate due to dependences (up to 15%), challenging STLS systems.
- One additional synthetic benchmark, FAST, to measure TLS overheads.

Results #1: Scalability



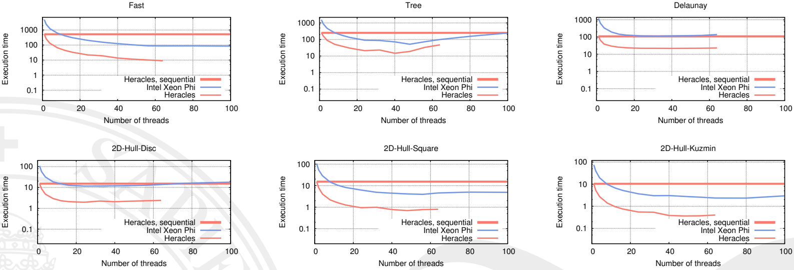
- **Scalability** is better for the Xeon Phi, thanks to its superior bandwidth.

Results #2: Using all threads of the Xeon Phi



- In general, performance degrades when launching more threads than processors: the 4-way SMT offered by the Xeon Phi is not useful in this case.

Results #3: Absolute performance



- True, our benchmarks do not benefit from vectorization.
- The Xeon Phi platform is consistently five times slower than our Intel Xeon shared-memory system (OOO execution, higher clock speed).

Conclusions

- The Xeon Phi was too good to be true: Hundreds of CPU-like threads for just € 1 500!
- However, absolute performance for ATLaS (in the end, an OpenMP application) is five times poorer than when using a good shared-memory system.
- The scalability is really good: The problem are the processors.
- We are aware that our parallel code does not need vectorization.

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- Our "Wish List" for future releases of the Xeon Phi regarding to TLS:
  - Faster computational units.
  - Out-of-order execution.
  - Some hardware support for TLS would help a lot.

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