Shared Memory Models

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for Parallel Programming Models

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S-DSM Motivation

- Shared memory an attractive programming model
  - » Familiar to users of SMPs and multi-threaded languages
  - » Arguably simpler than message passing, esp. for non-performance-critical code
  - » Has the potential to out-perform inspector-executor code for irregular access patterns, esp. with compiler support
- Outline
  - » Brief history
  - » Current state of the art
  - » Obstacles to better performance
  - » Wish list for communication architectures
  - » Plug for InterWeave

A Brief History of the Field

- 1986 Ivy
- 1989 Shiva
- 1990 Munin
- 1992 LRC (TreadMarks)
- 1993 Sh. Regions, Midway
- 1994 AURC (Shrimp)
- 1995 CRL
- 1996 Shasta
- 1997 Cashmere
- 1998 HLRC
- 2000 InterWeave

The original idea (Kai Li)

Relaxed memory model, optimized protocols

Software-only protocols

★ Leverage special HW (User-level messages, multiprocessor nodes)

S-DSM for SANs

- Relaxed memory model: multi-writer release consistency, data-race-free applications
- “Moderately lazy” protocol with home nodes: propagate updates and write notices at release time
- Page-size coherence granularity (false sharing not a major issue)
- VM-based write detection
- Multiprocessor nodes
- User-level network interface
- Exemplars: Cashmere, HLRC/GeNIMA

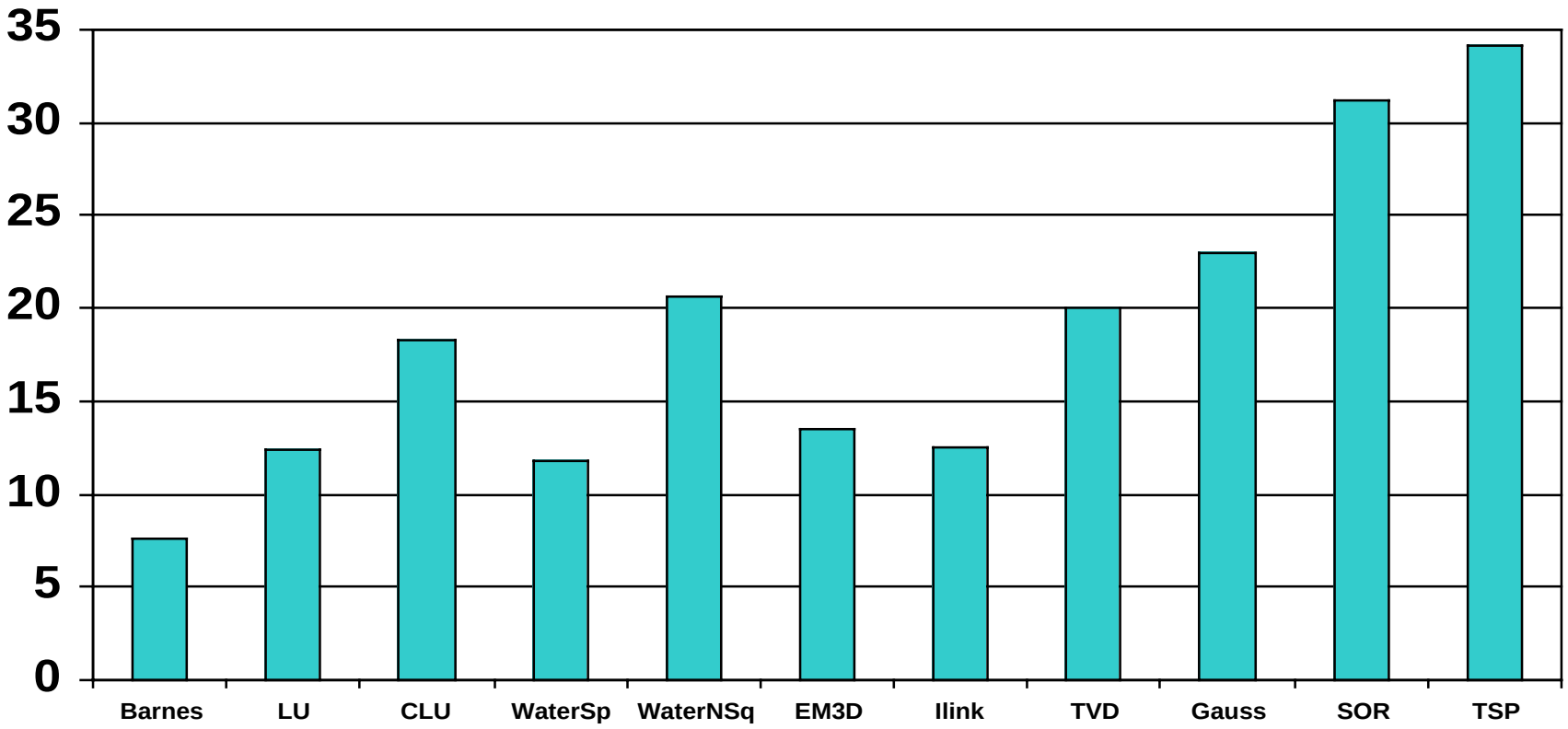
The Bad News

- The key ideas seem to have been discovered; the rate of innovation is way down
- Program committees aren't looking for papers
- No massively parallel apps
- No major OS vendor packages S-DSM (TreadMarks the only commercially-available system; optimized for high latency messages)
- High-end users (who might tolerate research code) still stick to MPI

The Good News

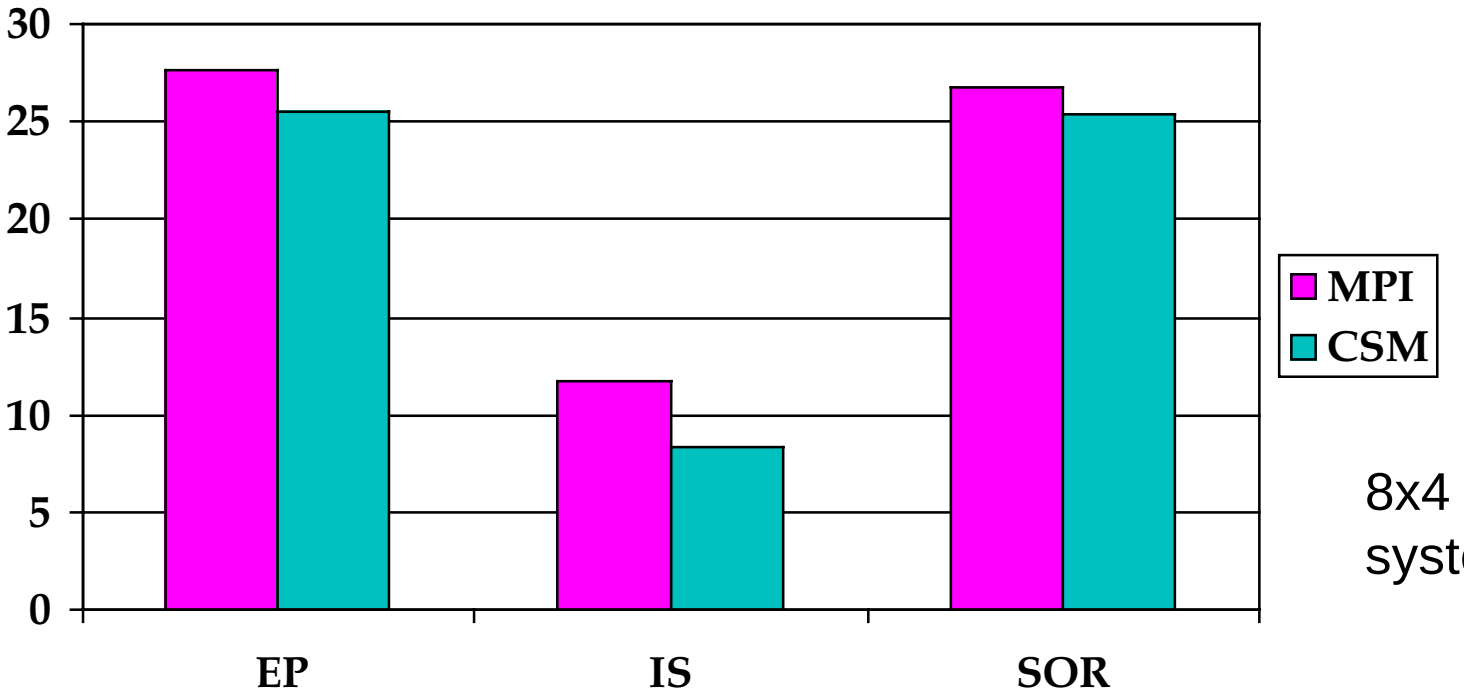
- Speedups for well-written apps are quite good
- Widespread use awaits production-quality systems
- Performance may improve with compiler support and better communication architectures
- The ideas are valuable in a wider domain; hence InterWeave (see plug at end)

Cashmere Speedups



8x4 Alpha system

Cashmere and MPI



8x4 Alpha system

- Lu et al report similar results for TreadMarks & PVM

Obstacles to Better Speedup

① False sharing (not as serious as once thought)
② Write detection overhead (twins, diffs, faults)
③ Maximum one-page message size
④ All “pull”-based — no “push” (opposite of most HW)

- 2, 3, and 4 amenable to compiler support
- 2, 4, and maybe 3 to protocol improvements
- 2 and 4 to hardware support

Communication Features

- ★ Low latency
- ★ Fast interrupts
- □ Remote writes
- □ Reliable delivery, total order
- ➡ Broadcast
- ➡ Remote reads, RMW (e.g. CAS)
- ➡ Very large address space, shadow page tables
- ▭ Fine-grain protection [UWisc], HW write detection [Bianchini], true HW coherence

★ crucial
□ useful
▭ probably impractical
➡ stay tuned

Cashmere Protocol Variants

- "Memory Channel" Cashmere
  - » shared data propagation (diffs)*
  - » meta-data propagation (directory, write notices)
  - » synchronization mechanisms (locks, barriers)

  ** Remotely-accessible shared data space is limited*

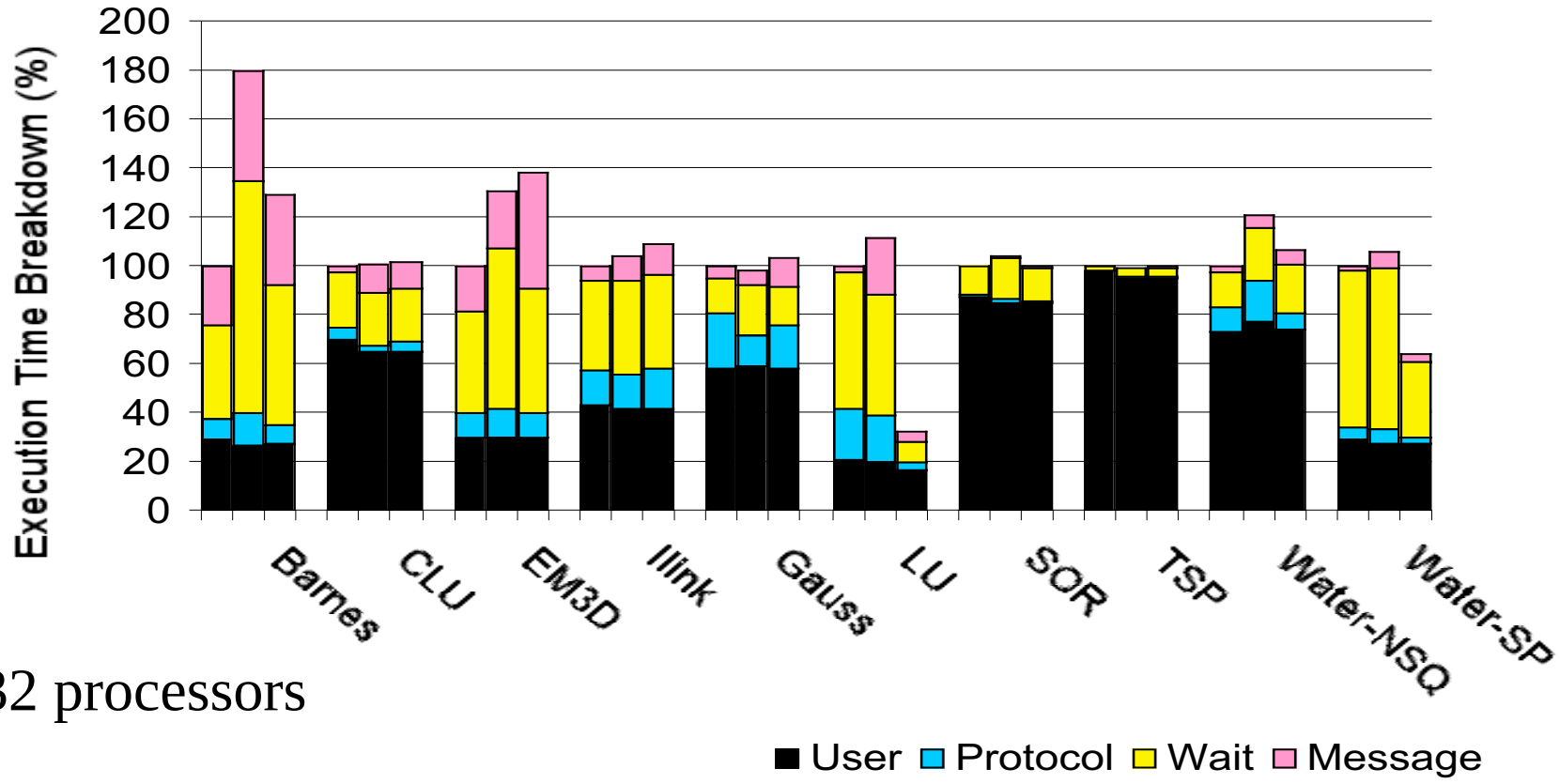
- "Explicit messages" Cashmere
  - » diffs, write notices, locks, barriers: use plain messages
  - » directory: maintain master entry only at the home
  - » hide ack latency by pipelining diffs, write notices

Free Home Node Migration

- Reduce twin/diff overhead by *migrating* home node to the active writer
  - » migration is not possible when using remote write to propagate data
- Send migration request as part of each write fault
  - » home will grant migration request if it is not actively writing the page
  - » old node will forward any incoming requests to new home
- *Migration very effectively reduces twin/diff operations*

Relative Performance

Left, middle, right bars:
MC Features, Explicit Msgs, Explicit Msgs Migration



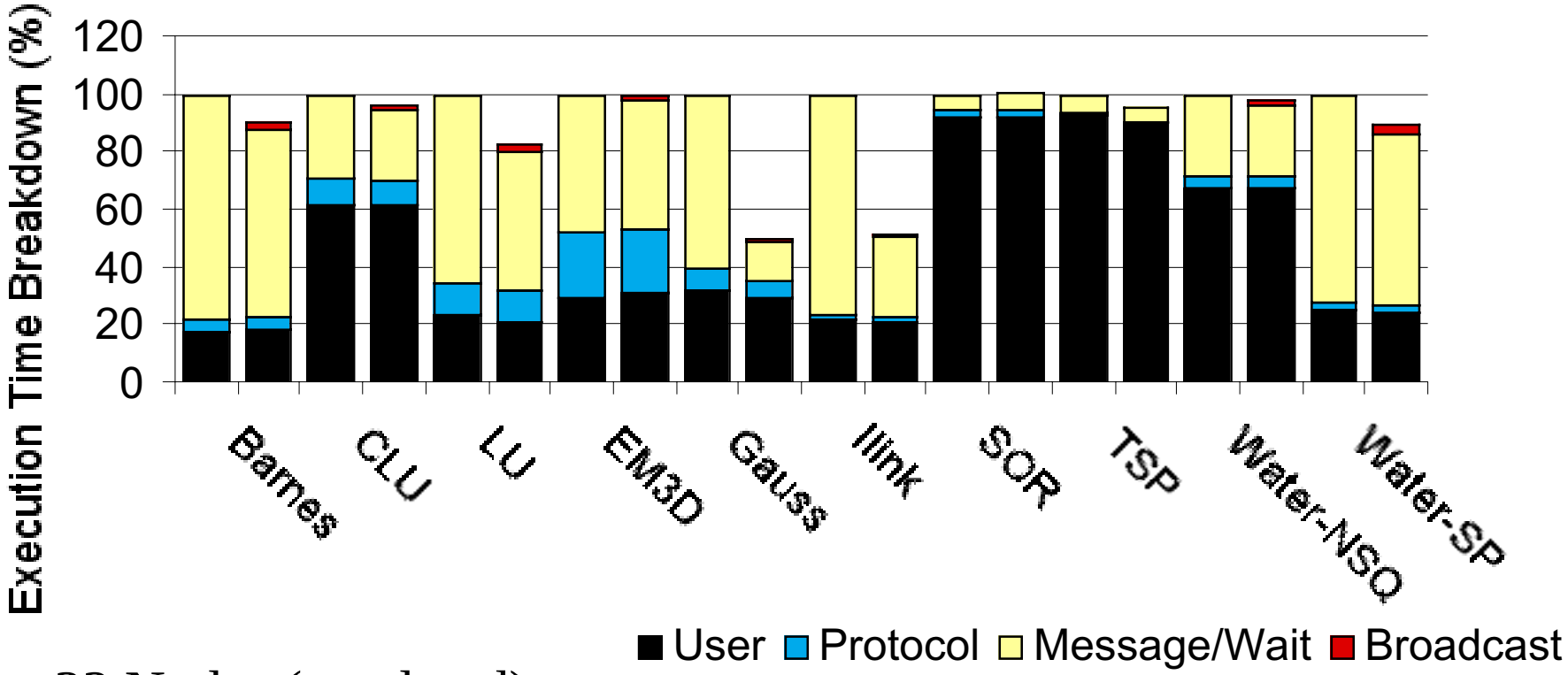
32 processors

Adaptive Broadcast

- Augment Cashmere with special broadcast buffers (don’t map shared memory directly)
- Use for widely-shared data
  - » multiple requests for page in a single synchronization interval
- Little performance improvement (<13%) on 8 nodes
- Sometimes significant improvement (up to 51%) on 32 (emulated) nodes

Relative Performance

Left, right bars: Cashmere, Cashmere-ADB



32 Nodes (emulated)

What Goes in the Network Address Space?

- Message buffers only
  - » Address space need not be huge
  - » Free home migration possible
- Application data
  - » Makes home node migration expensive
  - » Would benedit from remote reads and from very large network address space
  - » Requires pinning or dynamic virtual mappings
- Jury is still out; merits further study

Summary

- S-DSM a qualified success: familiar, simple, good for irregular apps or for SMP / CC-NUMA interoperability
- Significant opportunities for new communication architectures
  - » Fast interrupts
  - » Broadcast (used with discretion)
  - » Remote reads, atomic ops
  - » Very large network address space, dynamic virtual mappings
- Shows promise for geographically distributed systems: InterWeave

InterWeave Motivation

- Convenient support for “satellite” nodes
  - » remote visualization and steering (Astrophysics, ICF)
  - » client-server division of labor (datamining)
- ★ True distributed apps
  - » intelligent environments (AI group)
- Speedup probably not feasible; convenience the principal goal

InterWeave Overview

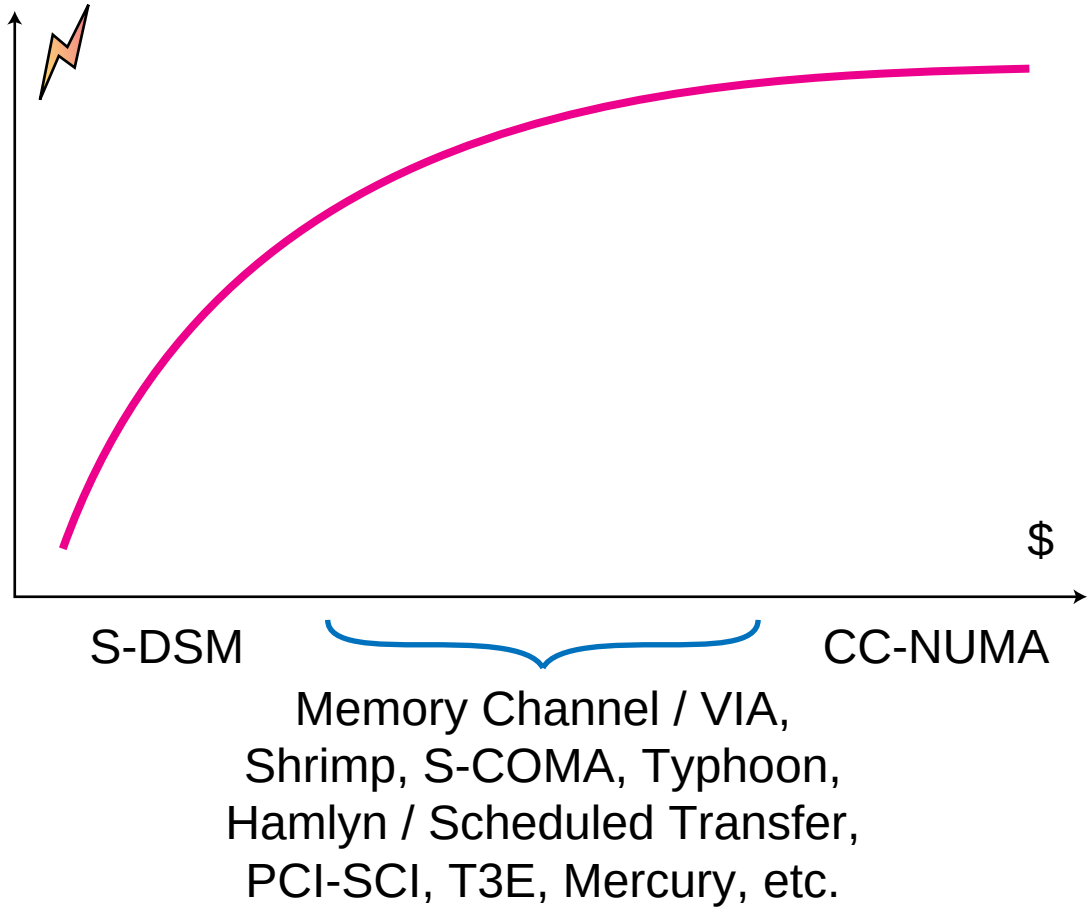
- Sharing of persistent versioned segments (heaps), named by URLs
- User-specified relaxed coherence; reader-writer locks
- Hash-based consistency
- Full support for language and machine heterogeneity, using IDL and pointer swizzling
- Cashmere functions as a single InterWeave node
- Fully compatible with RPC/RMI; supports true reference parameters

InterWeave Status

- Prototype running on Alpha/Tru64, Sun/Solaris, x86/Linux and Win2K (soon to be on Power-4/AIX);
- C, C++, Java, Fortran
- Funding from NSF & DOE/LLE
- Applications:
  - » Astroflow (stellar simulation)
  - » Barnes-Hut visualization
  - » incremental sequence mining
  - » distributed calendar
- In the works:
  - » distributed multi-player game (MazeWars)
  - » distributed object recognition (Smart Medical Home)

more info at
http://www.cs.rochester.edu/research/interweave

The Price-Performance Curve



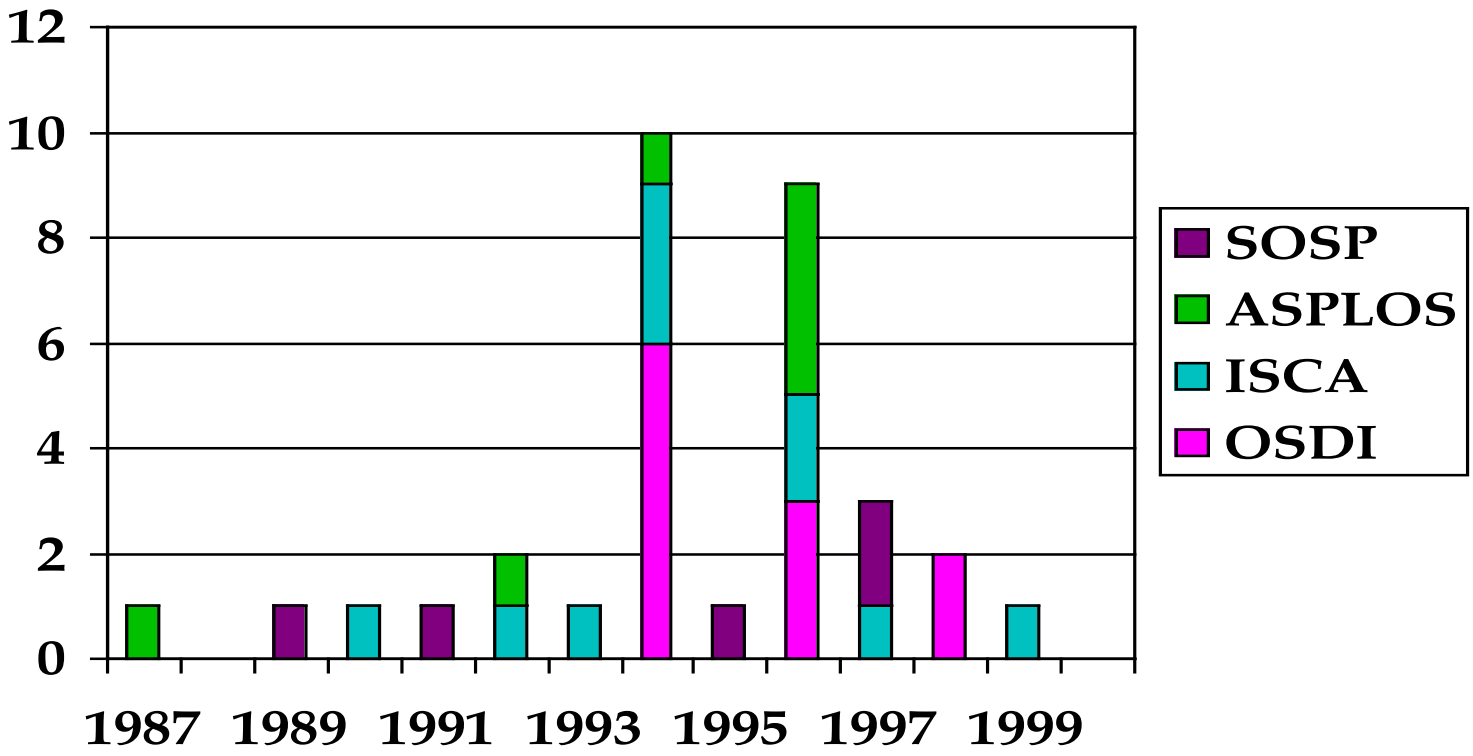
S-DSM may maximize “bang for the buck” for shared-memory parallel computing

The Fundamental Caveat

- Performance is maximized by unlimited programmer time coupled with a programming model that directly models the underlying hardware.
- S-DSM will not displace MPI at the National Labs anytime soon.

- Cf. the 1960s battle over compilation

Papers at Leading Conferences



Anybody see a trend?

Microbenchmarks

- AlphaServer 4100 cluster: 32 procs, 8 nodes
  - » Alpha 21164A 600 MHz
  - » Memory Channel II SAN
- Round-trip null message latency: 15 μsecs

	MC features (μ_{secs})	Explicit messages (μ_{secs})
Diff	31-129	70-245
Lock Acquire	10	33
Barrier (32 procs)	29	53

Segment Creation

```
IW_handle_t h = IW_create_segment (URL);
IW_wl_acquire (h);
my_type* p = (my_type *) IW_malloc (h, my_type_desc);
*p = ...
IW_wl_release (h);
```

- Communicates with server to create segment (checking access rights)
- Allocates local cached copy (not necessarily contiguous)
- Can follow pointers to other segments

Coherence

- Relaxed reader-writer locks
  - » Writer grabs current version (does *not* exclude readers)
  - » Reader checks to see if current cached copy (if any) is "recent enough"
- Multiple notions of "recent enough"
  - » e.g. immediate, polled, temporal, delta, diff-based
  - » from Beehive [Singla97], InterAct [LCR '98]
- Cache whole segments; server need only keep most recent version, in machine-independent form
- Diff-based updates (both ways) based on block time stamps

Consistency

- Need to respect happens-before
- Invalidate cached version of A that is older than version on which newly-obtained version of B depends
- Ideally want to know entire object history
- Can approximate using hashing
  - » slot *i* of vector contains timestamp of most recent antecedent hashing to *i*
  - » invalidate A if B.vec[hash(A)] is newer

InterWeave Related Work

- Distributed objects
  - » Language-specific (Emerald/Amber/VDOM, Argus, Ada, ORCA, numerous Java systems)
  - » Language-neutral (PerDiS, Legion, Globe, DCOM, CORBA, Fresco)
- Distributed state (Khazana, Active Harmony, Linda)
- Metacomputing (GLOBUS/GRID, Legion, WebOS)
- Heterogeneity, swizzling (RPC, LOOM, Java pickling)
- Multiple consistency models (Friedman et al., Agrawal et al., Alonso et al., Ramachandran et al., web caching work)
- Transactions, persistence (Feeley et al., Thor)