Overview of the PEBBL and PICO Projects: Massively Parallel Branch and Bound

Jonathan Eckstein
Business School and RUTCOR
Rutgers University

Joint work with a large team, mostly from Sandia National Laboratories, and in particular

William E. Hart
and
Cynthia A. Phillips

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(New) Distinction between PEBBL and PICO

Specific applications

PICO -- *Parallel Integer and Combinatorial Optimization*
Specific to mixed integer programming

PEBBL -- *Parallel Enumeration and Branch and Bound Library*
Generic parallel branch and bound

Until summer 2006, PEBBL was part of PICO

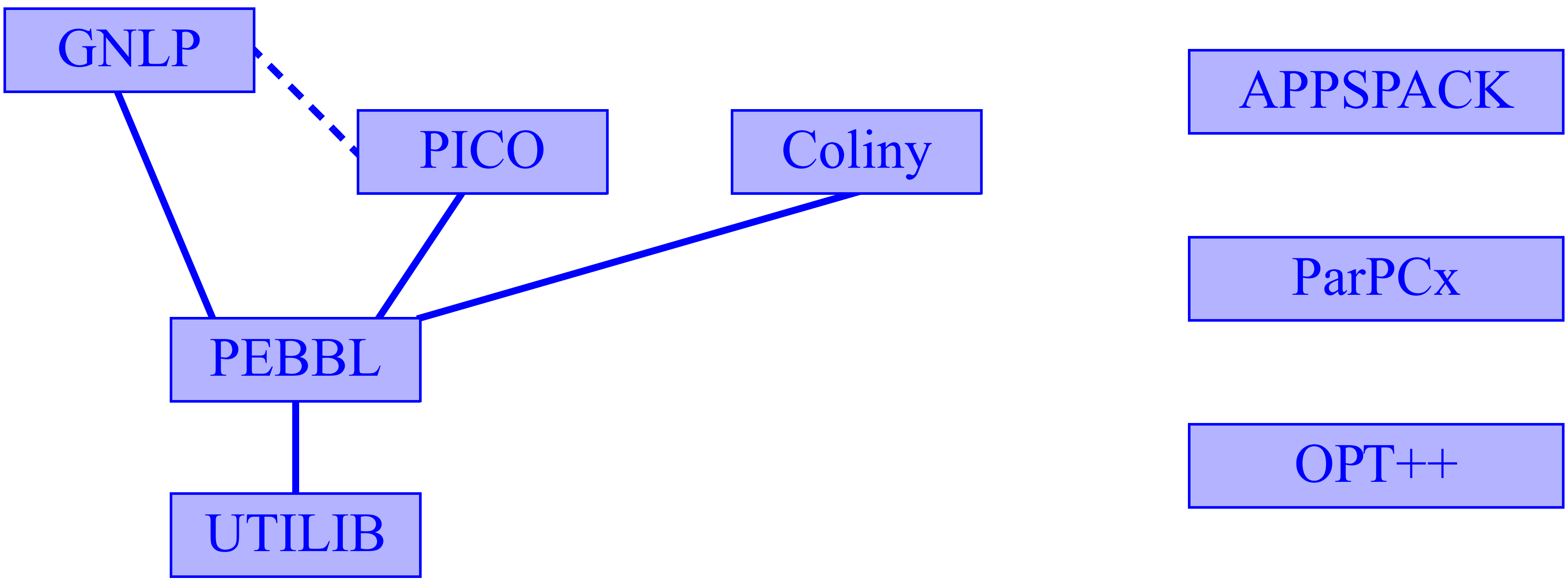
- PEBBL was called the “PICO core”
- What is now PICO was called the “PICO MIP”

PEBBL and PICO are part of ACRO

*A C*ommon *R*epository for *O*ptimizers

`http://software.sandia.gov/acro`

- Collection of open-source software arising from work at Sandia National Laboratories
- Generally lesser GNU public license



PEBBL/PICO Applications

Direct use of PEBBL

- Peptide-protein docking (quadratic semi-assignment)

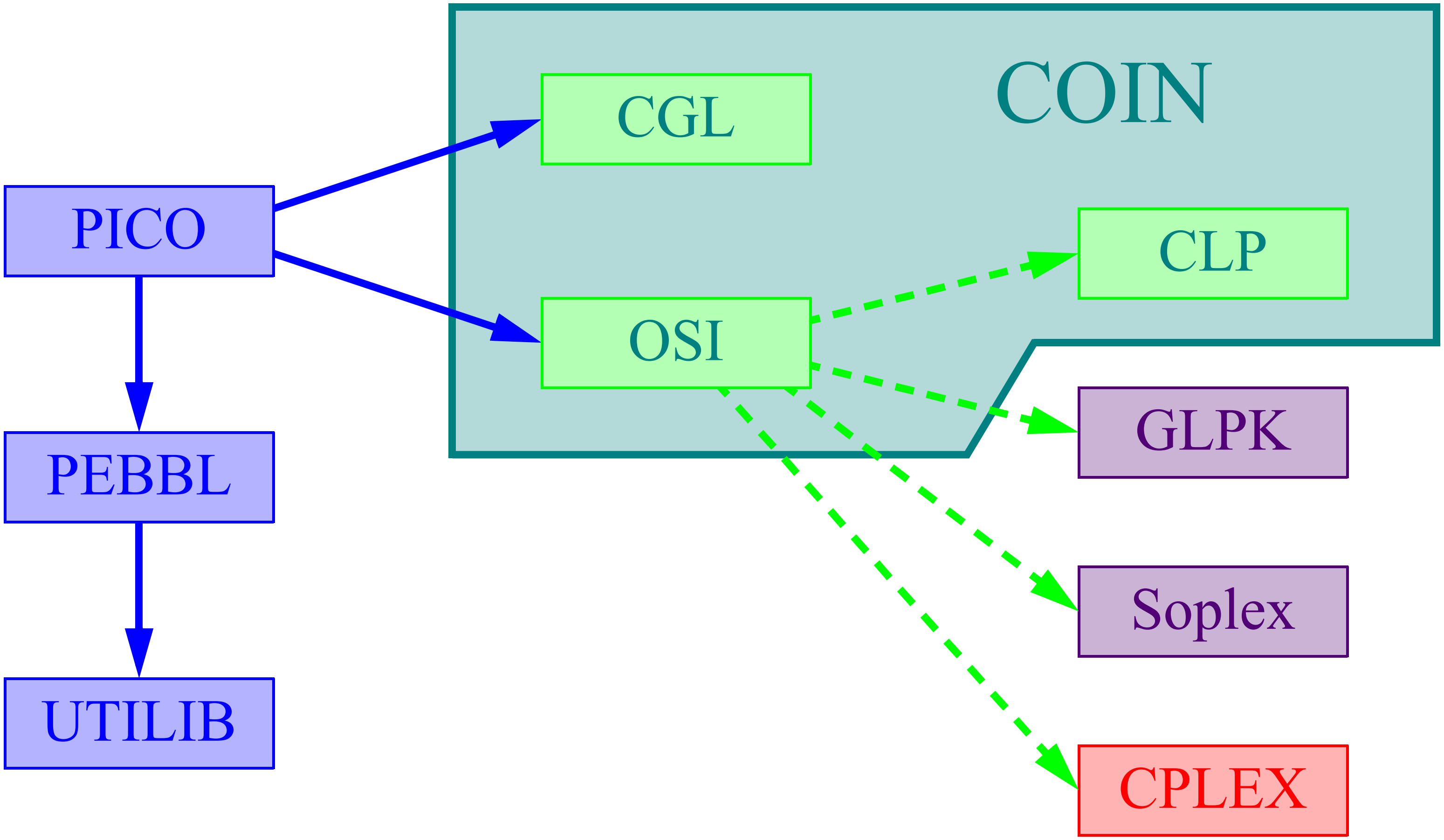
GNLP (includes PEBBL)

- PDE Mesh design
- Electronic package design

PICO (includes PEBBL)

- JSF inventory logistics
- Peptide-protein docking
- Transportation logistics
- Production planning
- Sensor placement
- ...

PEBBL/PICO Package Relationships



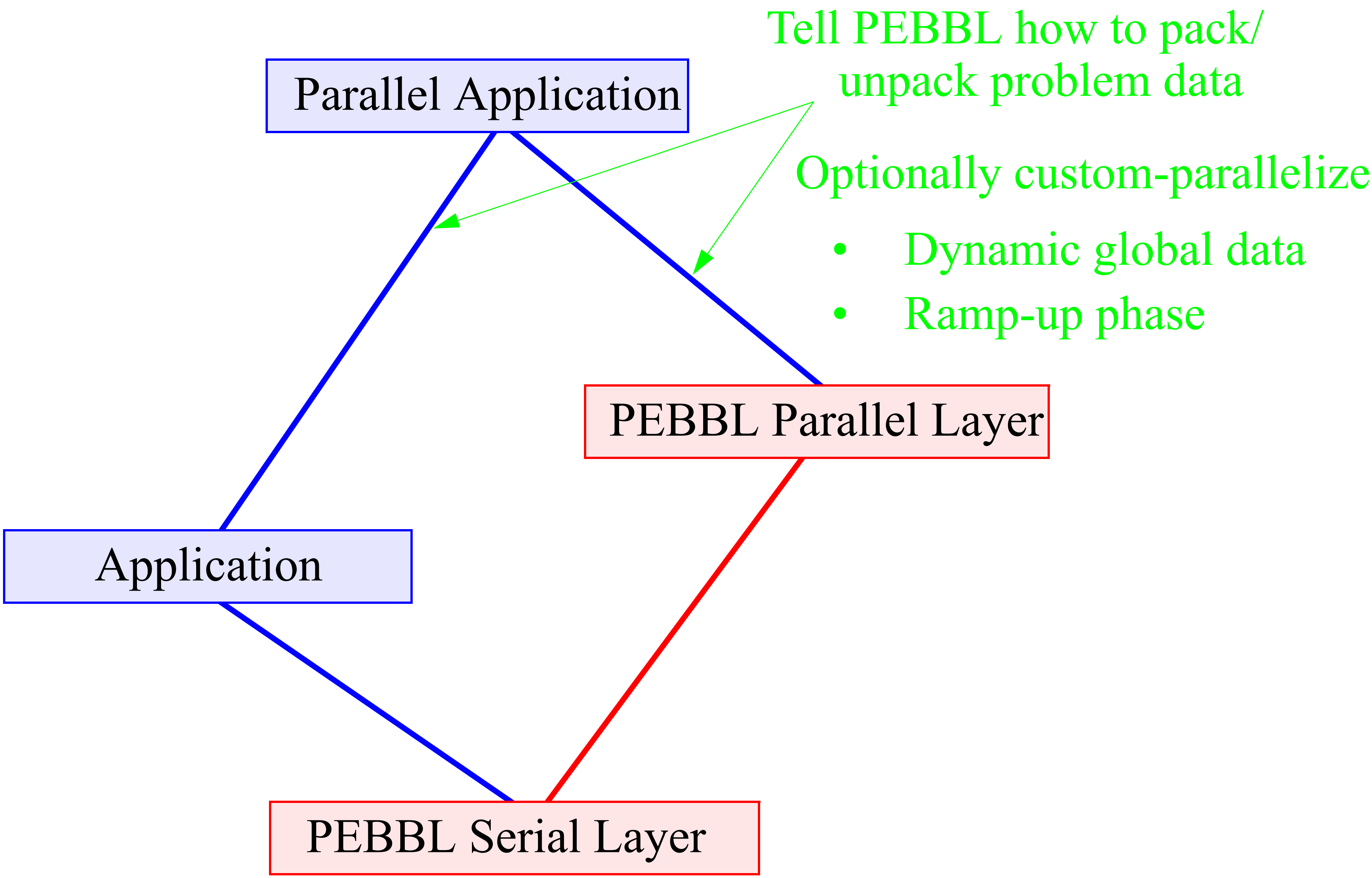
For remainder of talk, focus on PEBBL

PEBBL is a parallel "branch and bound shell"

Key features

- Object oriented design with serial and parallel layers
- Application interface via manipulation of problem states
- Variable search "protocols" as well as search orders
- Flexible, scalable parallel work distribution using processor clusters
- Non-preemptive thread scheduling on each processor
- Checkpointing
- (Enumeration support)
- Alternate parallelism support during ramp-up phase

Basic C++ Class Structure: Serial and Parallel Layers



PEBBL Structure: Serial and Parallel Layers
Application Development Sequence

Describe application to PEBBL

↓

Debug in serial environment

↓

Tell PEBBL how to pack and unpack problem/subproblem messages

↓

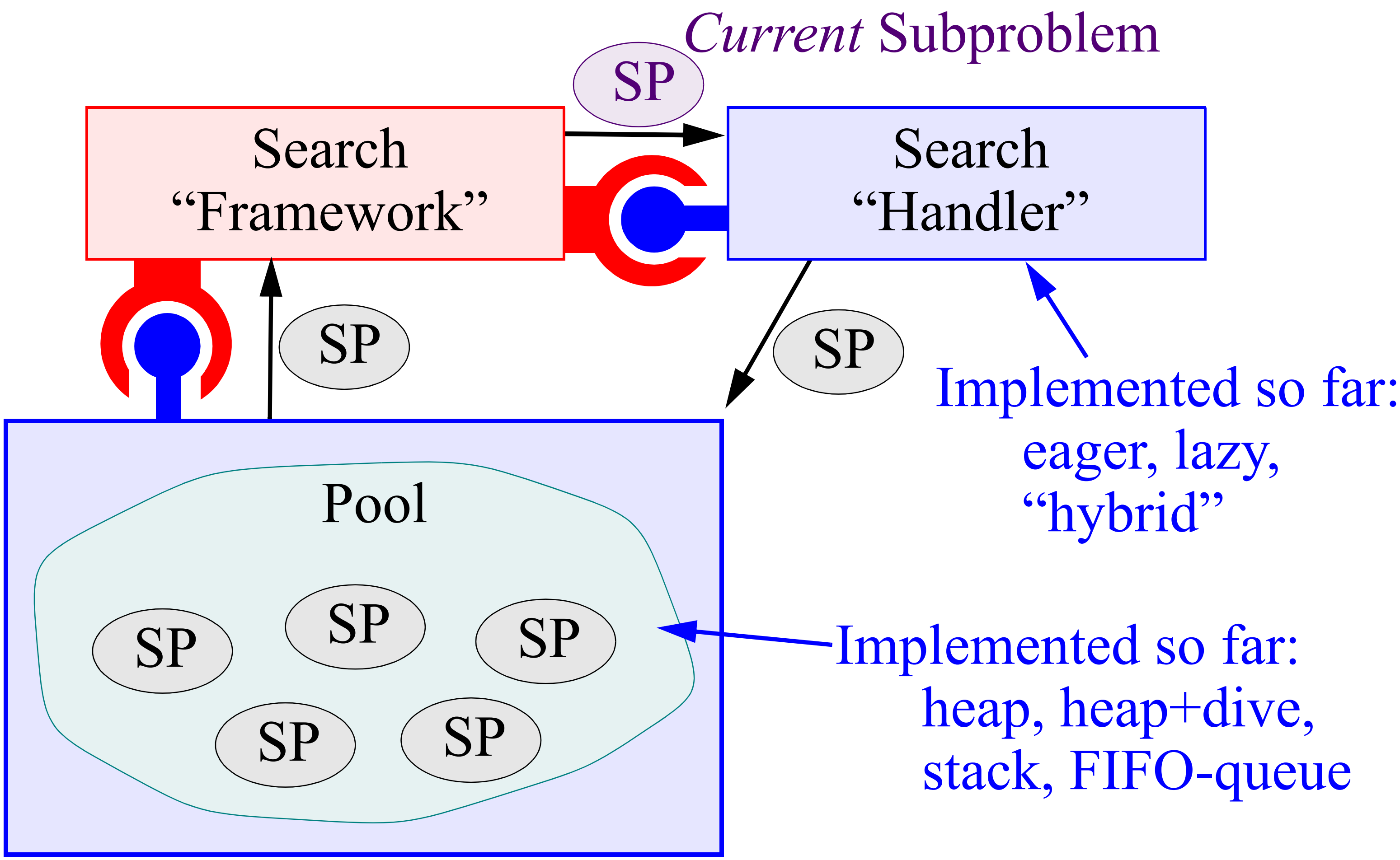
Run in parallel environment without additional programming effort

↓ (optional)

Enhance default parallelization: global information, ramp-up, etc.

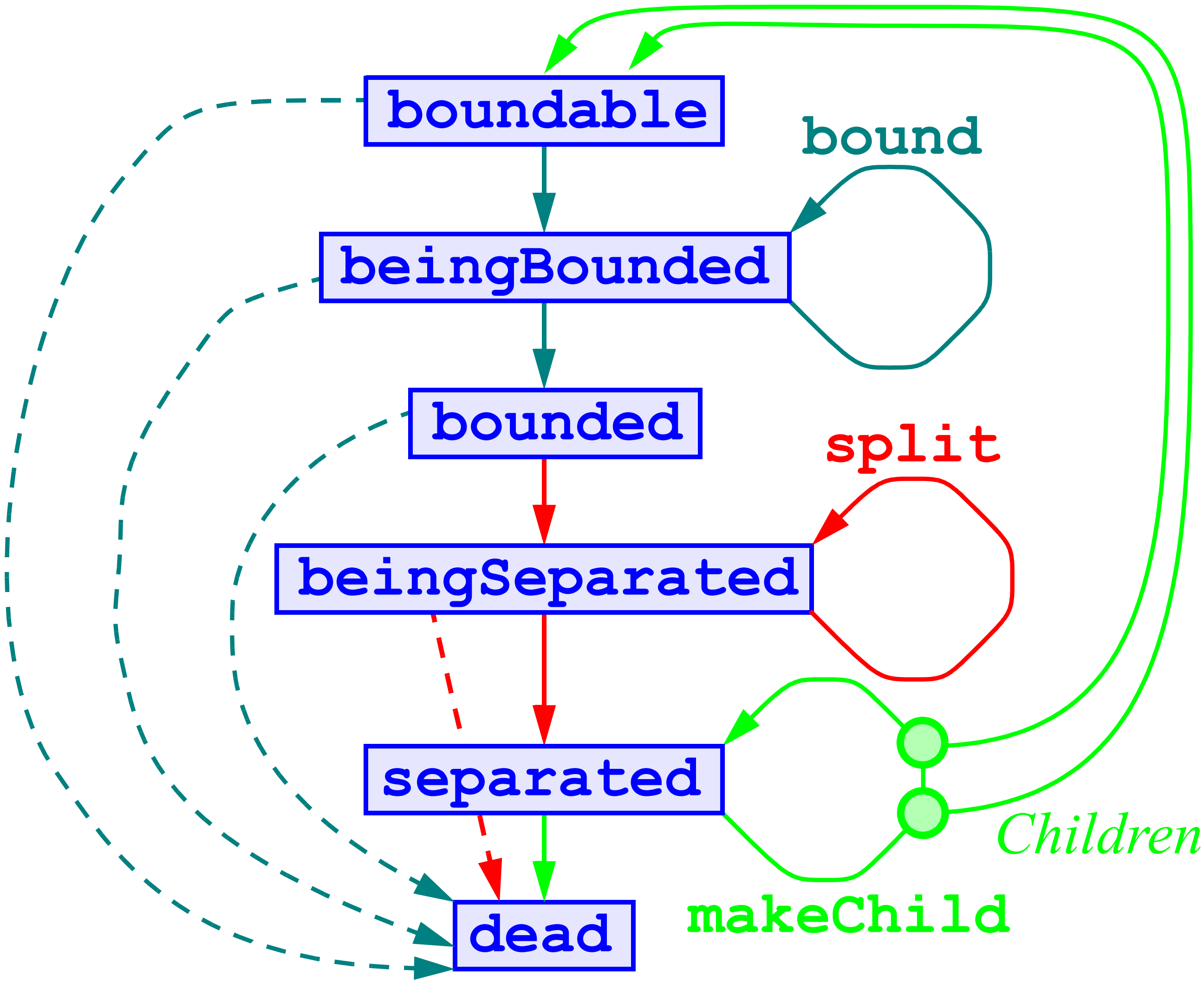
PEBBL Serial Layer Design

- Class derived from **`branching`** holds data global to problem.
- Class derived from **`branchSub`** holds subproblem data and pointer back to global data (as in ABACUS).



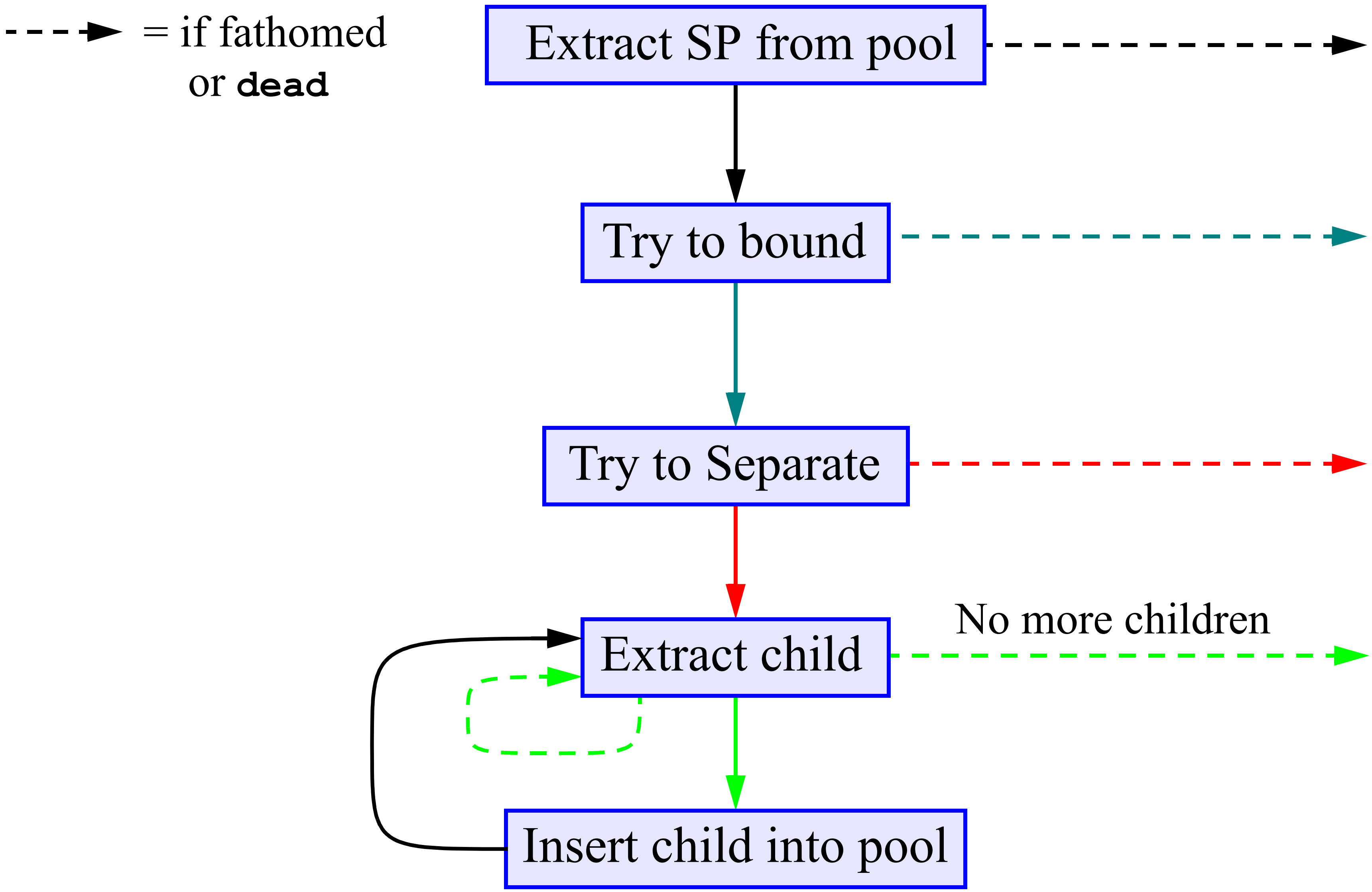
- Key point: problems in the pool remember their *state*.

Standard Subproblem State Sequence



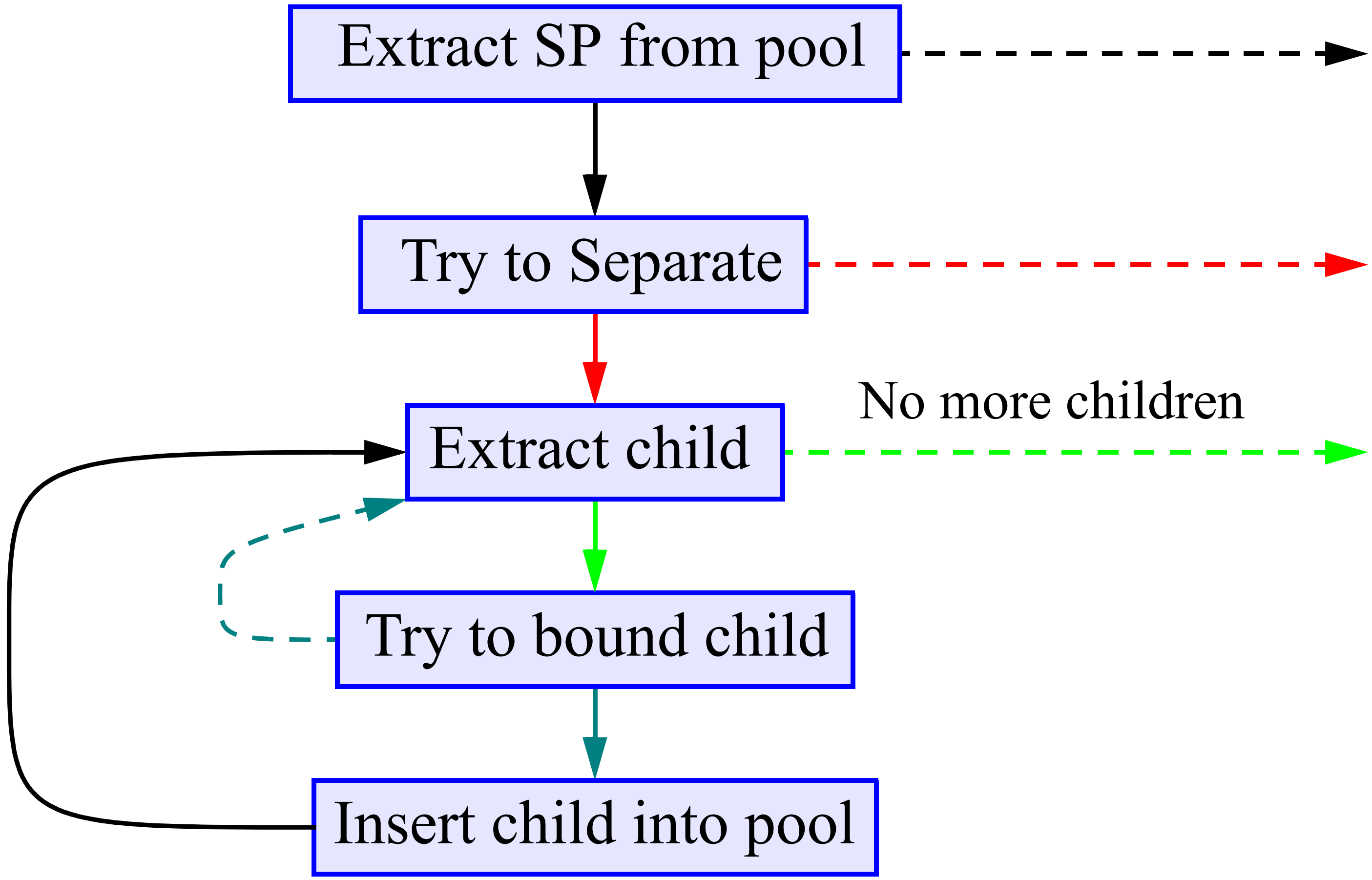
PEBBL interacts with the application solely through virtual functions that cause state transitions ( /  / )

Search Handler: Lazy



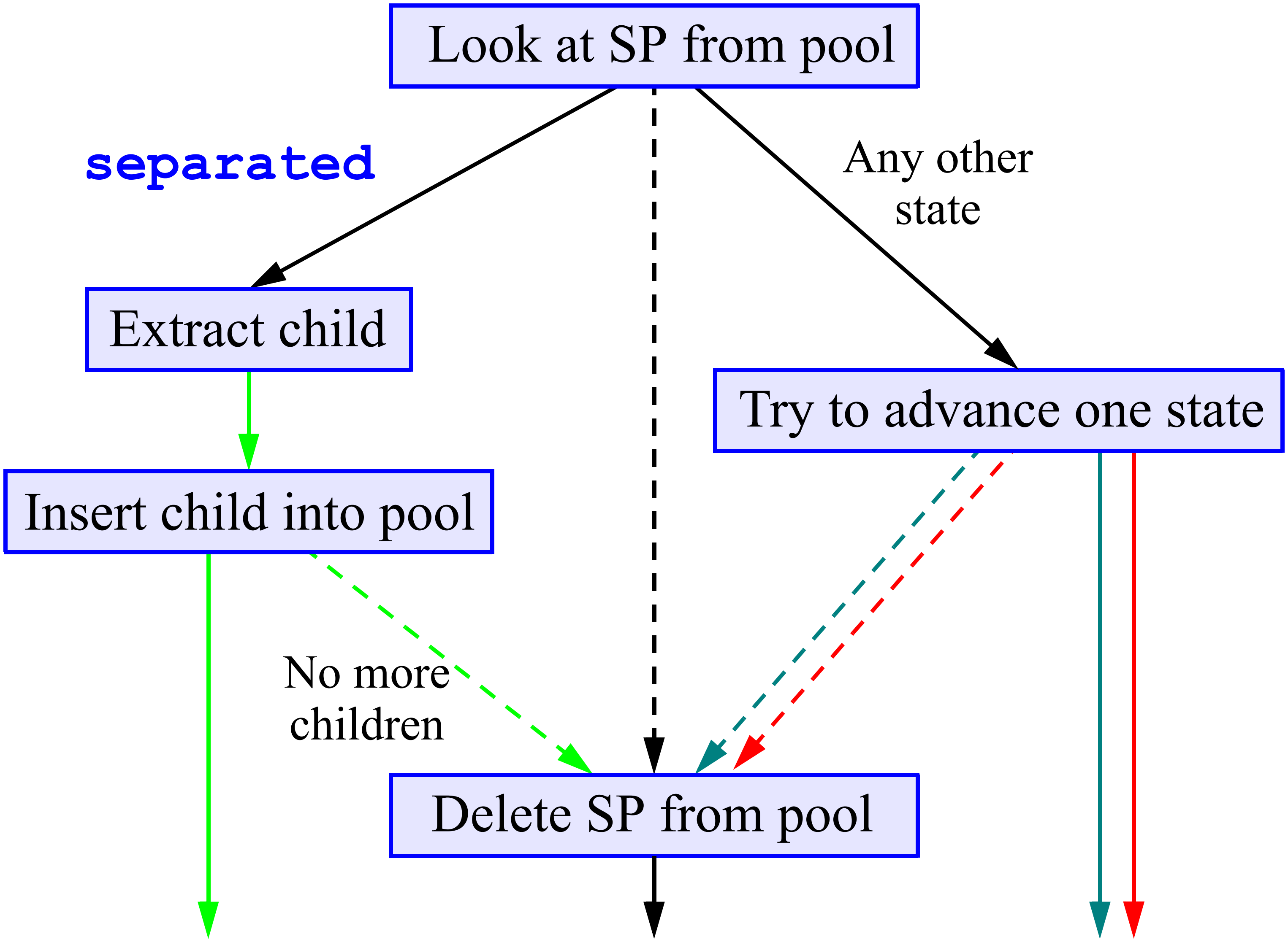
Pool consists of **`boundable`** subproblems

Search Handler: Eager



Pool consists of **`bounded`** subproblems

Search Handler: “Hybrid”/General



Pool can contain problems in any mix of states.

Generality of Approach

Naturally accommodates an wide range of branch-and-bound algorithm variations

Most known variations are possible by combining

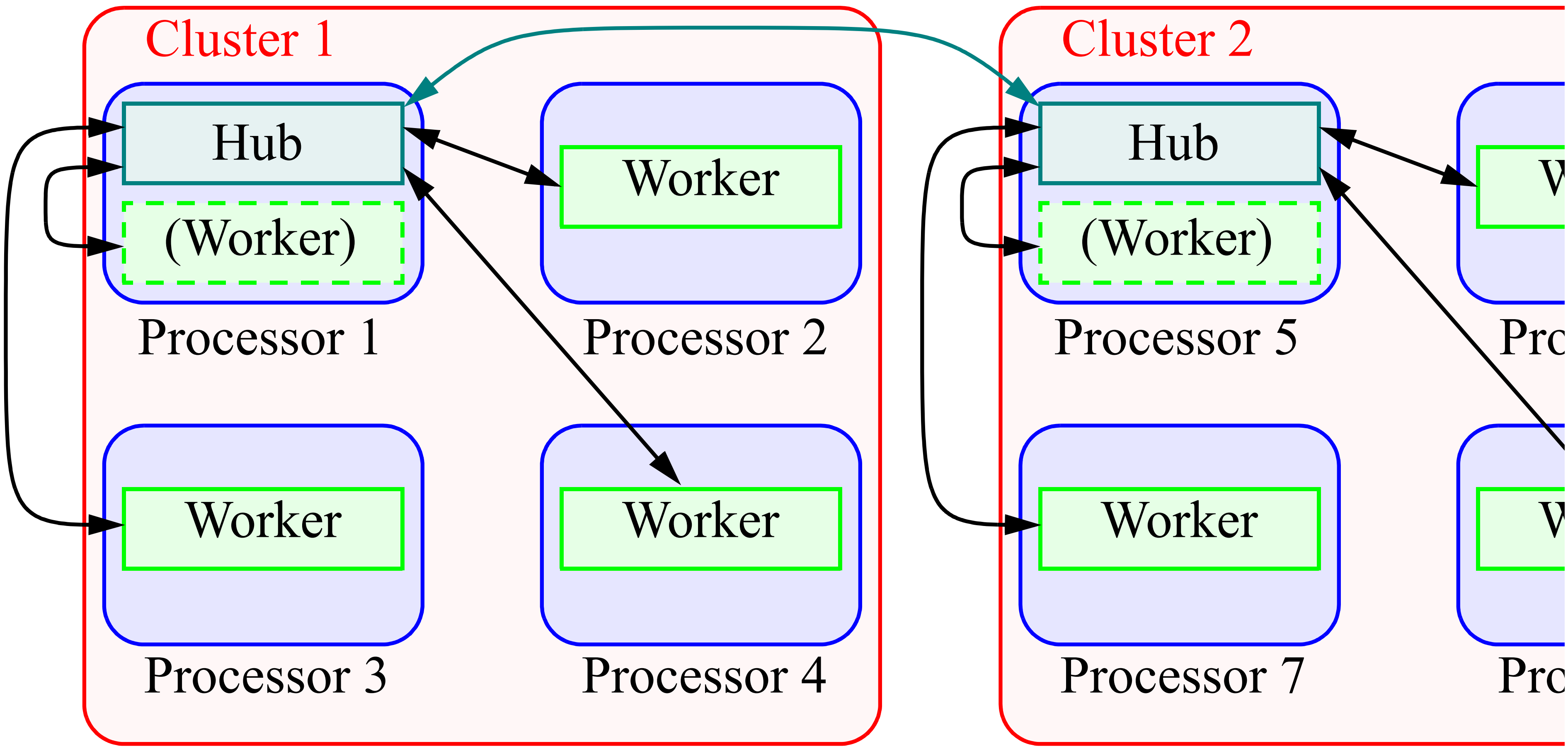
- Three existing handlers
- Stack and heap pools
- Proper implementation of virtual functions for application

Also:

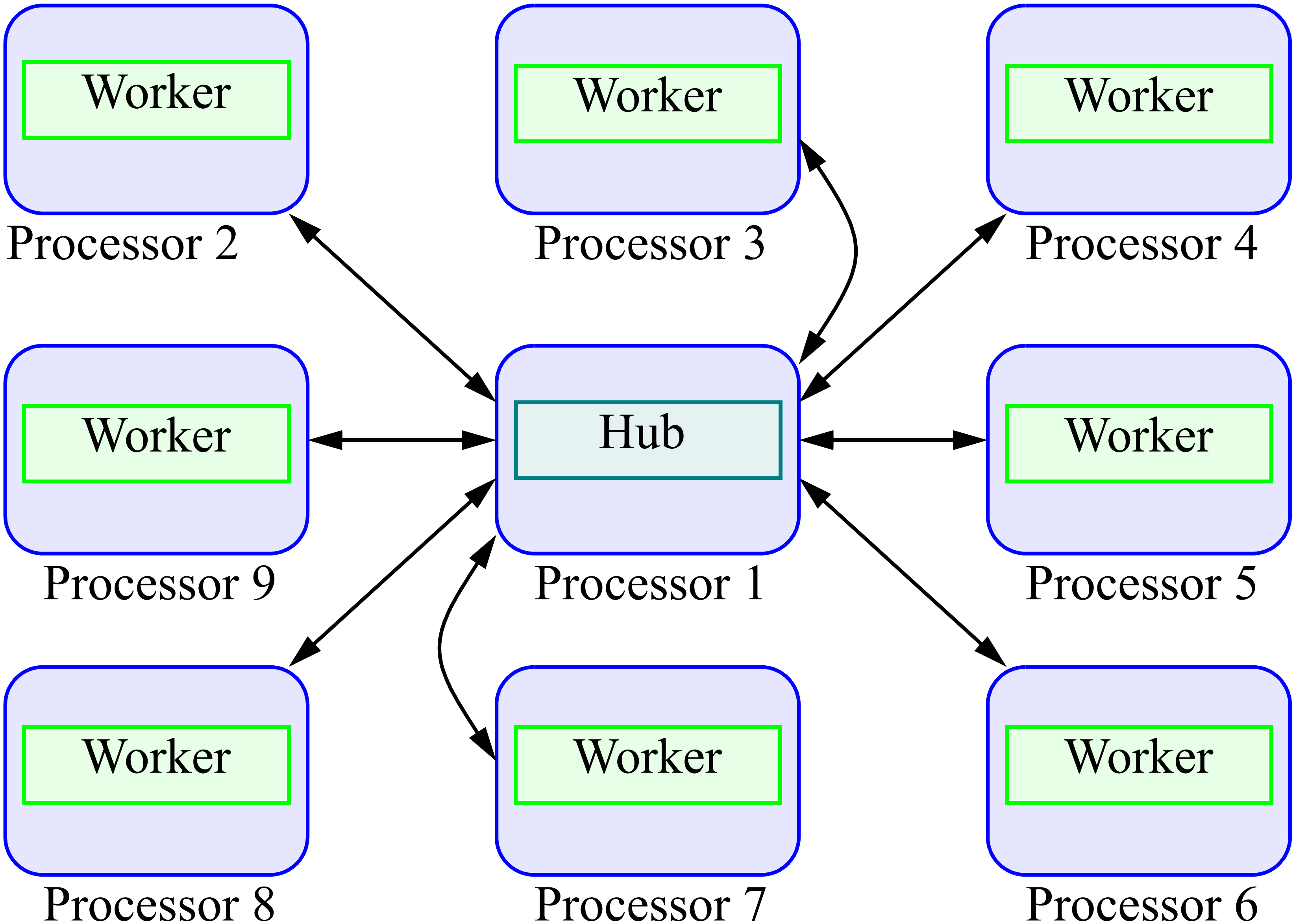
- Other pool implementations are possible
- Other handlers possible

Parallel Layer: User-Adjustable Clustering Strategy

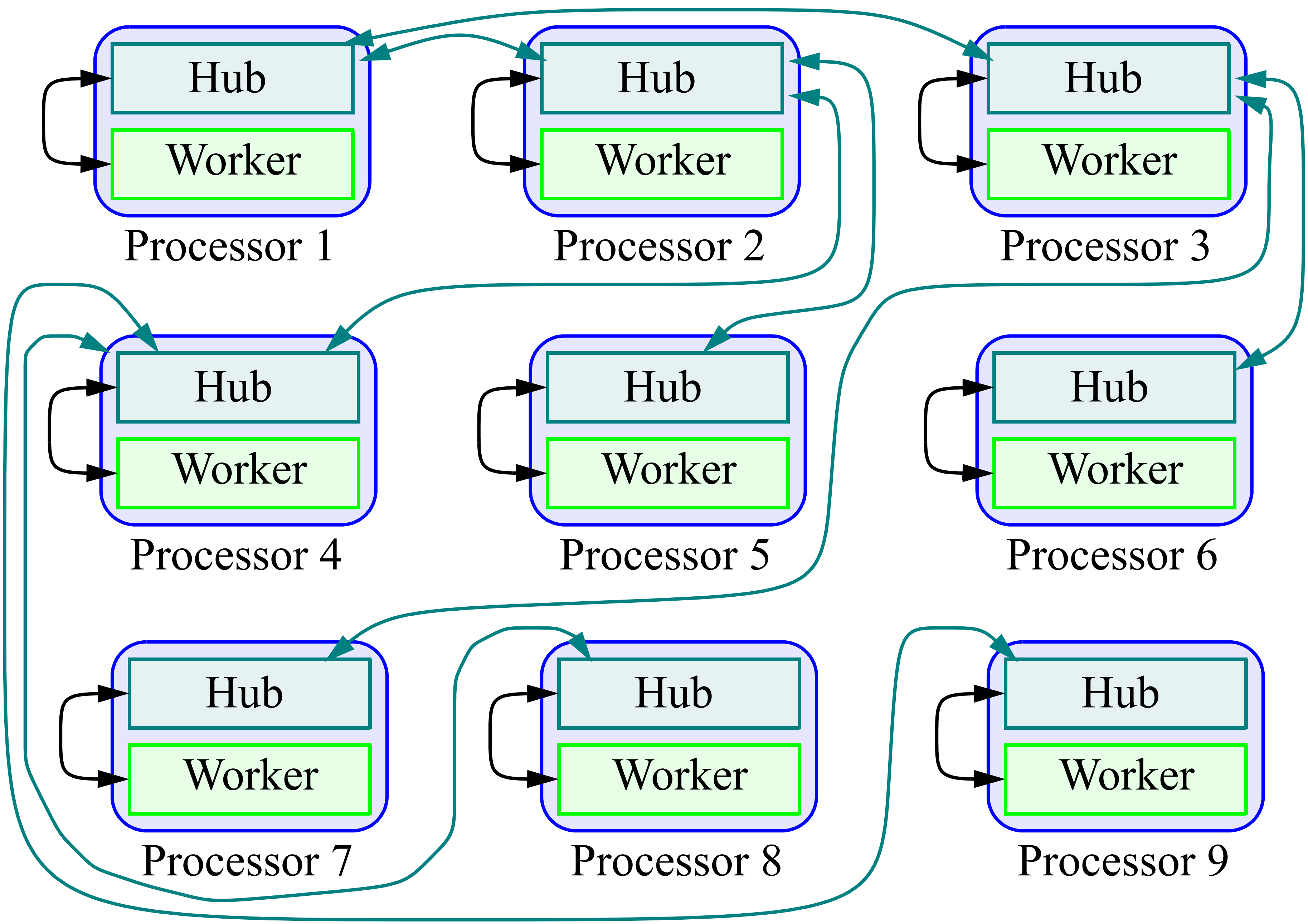
- Processors are collected into *clusters*
- One processor in the cluster is a *hub* (central controller for cluster)
- Other processors are *workers* (process subproblems)
- Optionally, a hub can be a worker too (depends on cluster size)



Extreme Case: Central Control



Extreme Case: Fully Decentralized Control



Work Transmission: Within a Cluster

Hub processes deal with *tokens* only. A token =

- # of creating processor
- Pointer to creating processor's memory
- Serial number
- Bound
- (Any other information needed in work scheduling decisions)

Prevents irrelevant information from

- Overloading memory at hubs
- Wasting communication bandwidth in and out of hubs

Remaining subproblem information sent directly between workers when necessary

Within a Cluster: Adjustable Behavior

Worker has its own local pool (buffer) of subproblems

Chance of returning a processed subproblem (or child) into the worker pool:

- 0% $\Rightarrow$ pure master-slave, hub makes all decision (fine for tightly-coupled hardware and time-consuming bounds).
- 100% $\Rightarrow$ hub "monitors" workers but doesn't make low-level decisions (better for workstation farms).
- Continuum of choices in between...

Backup "rebalancing" mechanism to make sure that hub controls enough subproblems

- Otherwise hub might be "powerless" in some situations
- Rebalancing uncommon for standard parameter settings

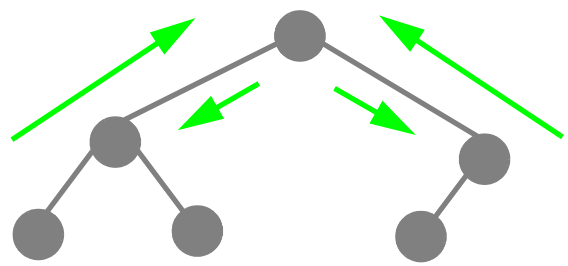
Work Transmission: Between Clusters

Load balancing between clusters via

- Random scattering upon subproblem creation, supplemented by...

Rendezvous load balancing:

- Non-hierarchical: there is no “hub-of-hubs” or “master-of-masters”
- Hubs are organized into a tree



- Periodic message sweeps up and down tree summarize overall load balance situation
- Efficient method for matching underloaded and overloaded clusters, followed by pairwise work exchange
- *Not* “work stealing” (receiver initiated)
- *Not* “work sharing” (sender initiated)

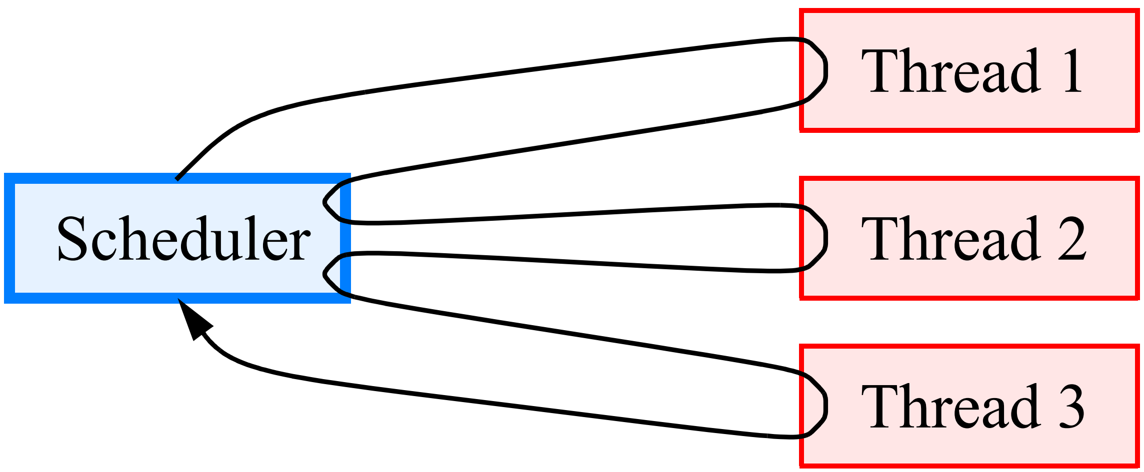
Non-Preemptive Threads on Each Processor

Each processor must do a certain amount of multi-tasking

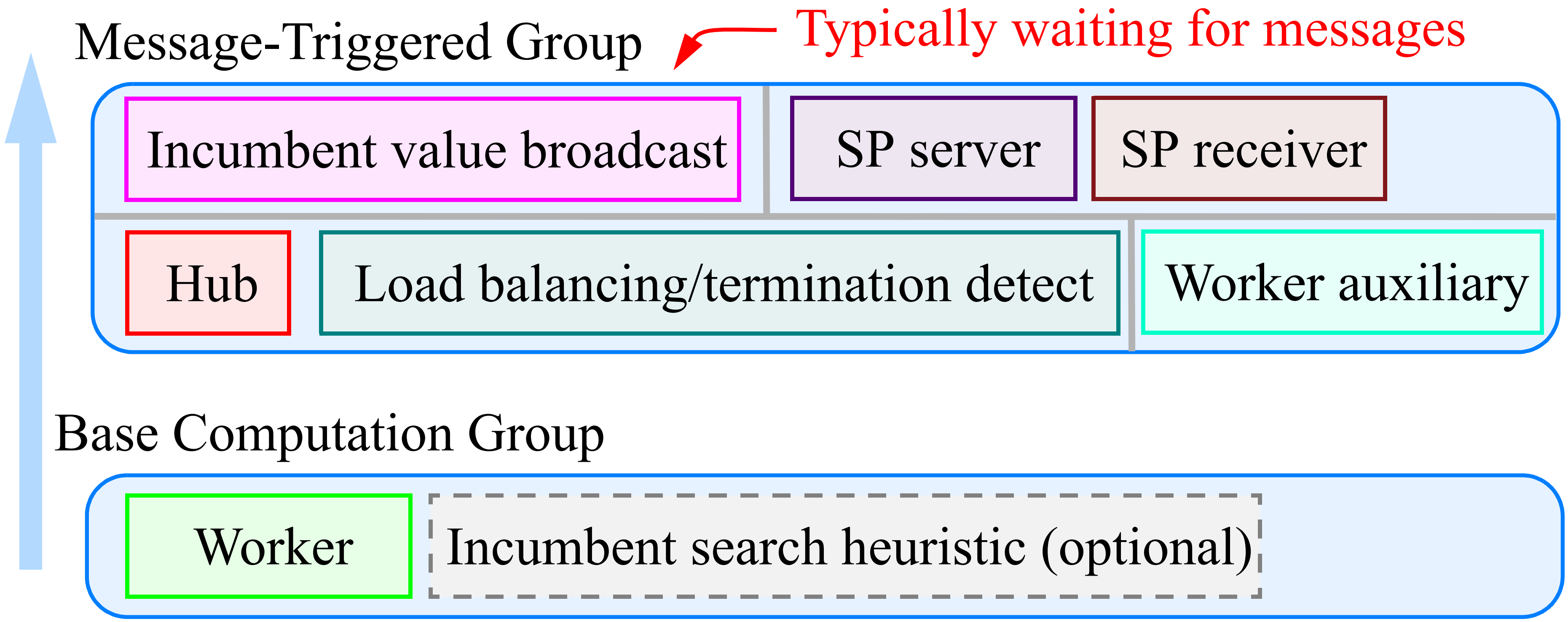
Schedule multiple *threads* of control within each processor

- Each task gets a thread.
- Threads can share memory.
- We use a *scheduler* to allocate CPU time to threads.

Scheduler uses non-preemptive multitasking approach (*à la* old Macs, Win 3.*x*):



Base Scheduler Setup



- Upper group: each thread waits for a specific kind of message
  - Wakes up; processes message; posts another receive request; sleeps again
- Base group: usually ready to run
  - ***Worker*** does work usually handled by serial layer
  - Continuously adjusts amount of work at each invocation to try to match a target ***time slice***
  - CPU time allocated in specifiable proportion via ***stride scheduling***

Incumbent Search Thread

Implements application-specific search heuristic; could be:

- Tabu
- GA
- etc...

Can send messages to other processors

- *e.g.* a parallel GA

Has small quantum for easy interruption

Soaks up cycles when worker thread is blocked or waiting

Can adjust priority as run proceeds

- High early on
- Lower later when we’re probably just proving (near) optimality of current incumbent

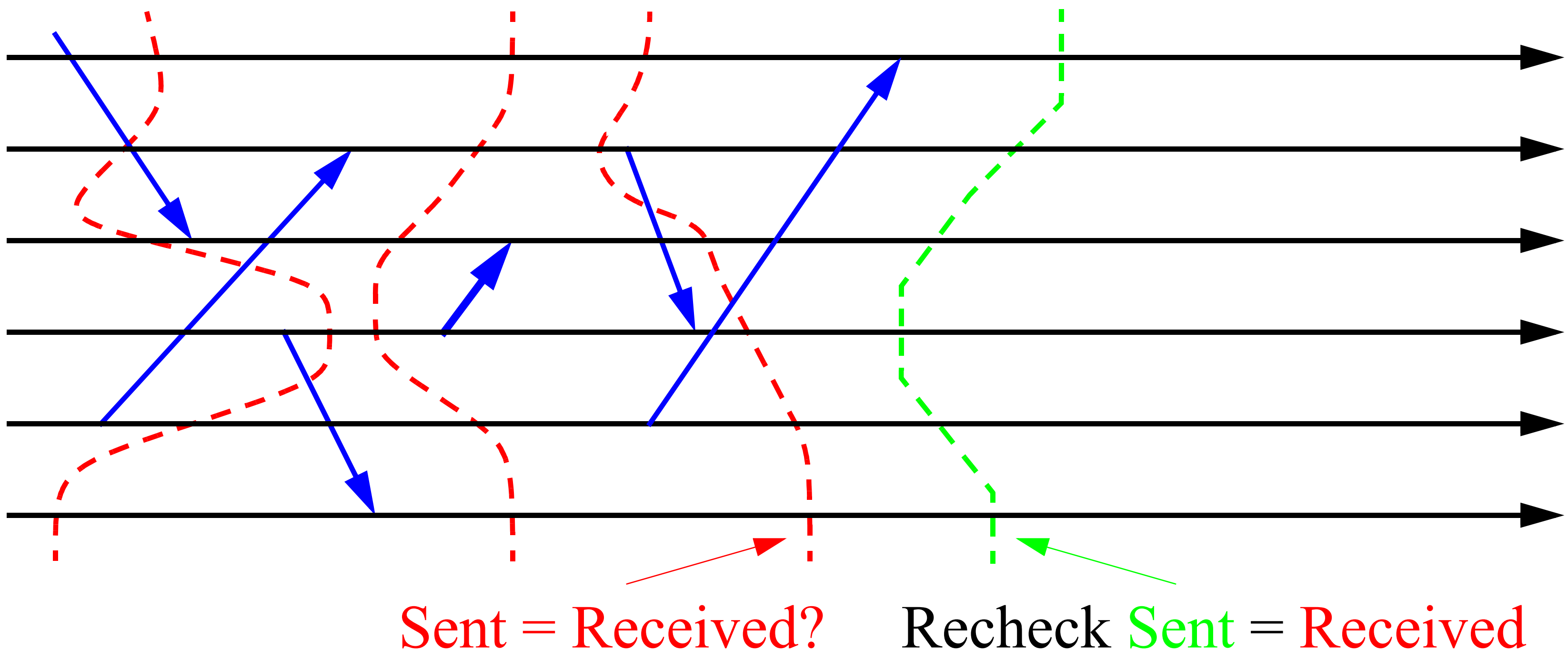
Framework allows smooth blending of parallel search heuristics with branch-and-bound.

General issue with asynchronous message-passing programs.

Make sure:

- All the work is really gone
- There are no stray unreceived messages floating around

PICO uses the “four counters” method of Mattern *et. al*



Handled by load balancing thread

Checkpointing (Relatively New)

- Systems crash
- Jobs exceed time quotas, ...

Don't want to lose all your work when that happens!

- Periodically save state of computation
- Later, you can restart from the saved state

Implementation in PEBBL:

- Load balancer message sweep signals it's time to checkpoint
- Workers and hubs turn "quiet": don't start new communication
- Use standard termination check logic to sense when all messages have arrived
- Each processor writes a (possibly local) checkpoint file

Restart options

- Normal: each processor reads its own file (possibly in parallel)
- Read serially, redistribute -- allows different number of processors

Ramp-Up: Starting the Search

There may be multiple sources of parallelism in *any* branch and bound application (not just MIP):

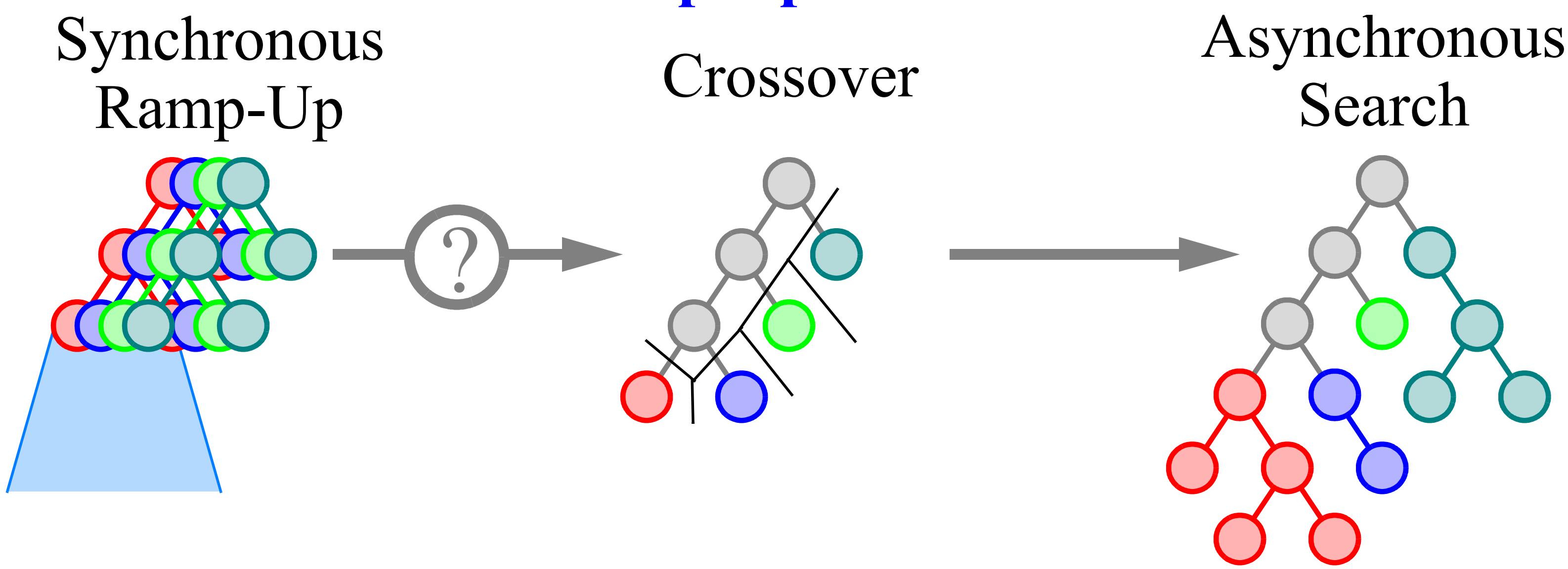
- Parallelism from large search tree (generic)
- Parallelism *within* each subproblem (application-specific)

Early in the search

- Tree is small
- Within-subproblem parallelism may be especially large
- So, there may be more parallelism available within subproblems than from the tree
- You also might not want to exploit tree parallelism too aggressively (likely to work on “non-critical” nodes)

Eventually, tree parallelism will probably dominate (and be safe)

Generic Ramp-Up Mechanism



- *Ramp-Up:* all processors redundantly develop top of tree, synchronously parallelizing some of each subproblem's work
- Virtual function decides when tree parallelism is likely to be better
- *Crossover:* partition tree evenly (no commucation!)
- Then start usual *asynchronous search* (different processors look at different leaves of the tree)
- PICO uses this feature: parallelizes strong-branching-like pseudocost initialization until tree offers more parallism

PEBBL and PICO Availability

ACRO 1.0 available first week of August, 2006

http://software.sandia.gov/acro

Lesser GNU public license

Includes PEBBL 1.0 release:

- Should be stable
- Contains 57-page user guide (will probably grow soon)
- Also, feel free to contact us if interested

PICO -- areas that need more work:

- Cut finders (improve/replace current CGL finders)
- Cut management
- Incumbent heuristic (fairly extensive work done, but more needed)