Parallel Runtimes: Cilk

Chris Rossbach & Calvin Lin

cs380p

Outline

- Background
- Cilk
    - DAG-based computation
    - Critical Path
    - Work-stealing
    - Continuation-passing

Review: Decomposition

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Domain v. Functional

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- a.k.a. Data Parallel
- Input domain
- Output Domain

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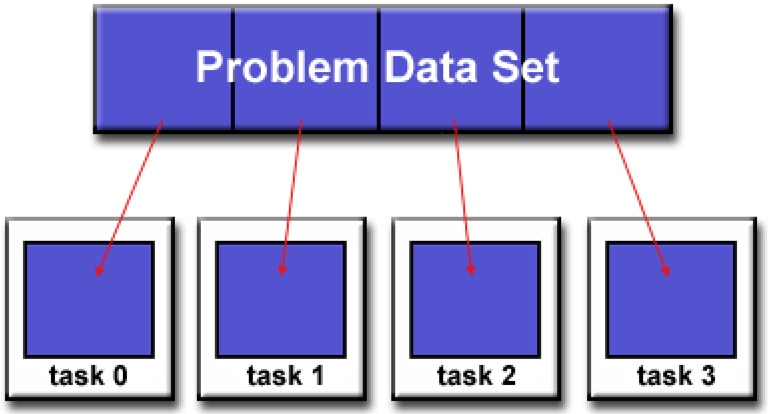

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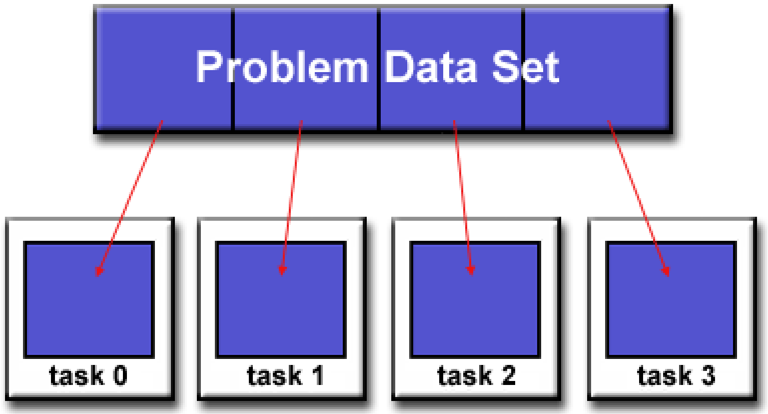
- Pipelining



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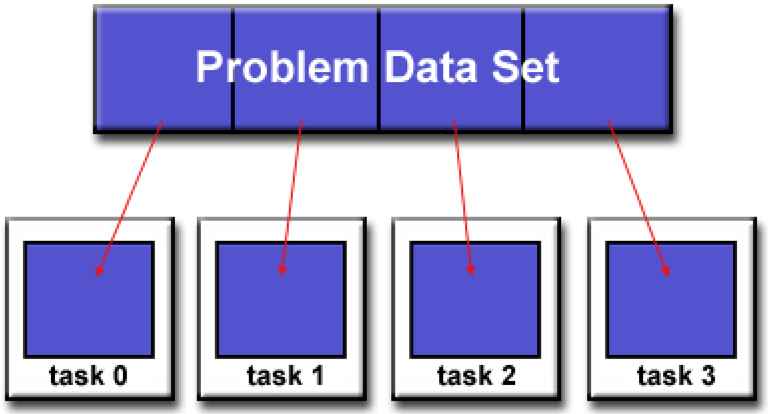

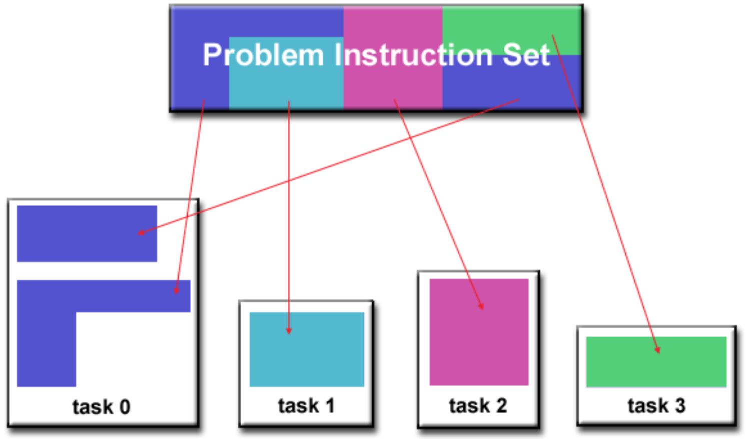

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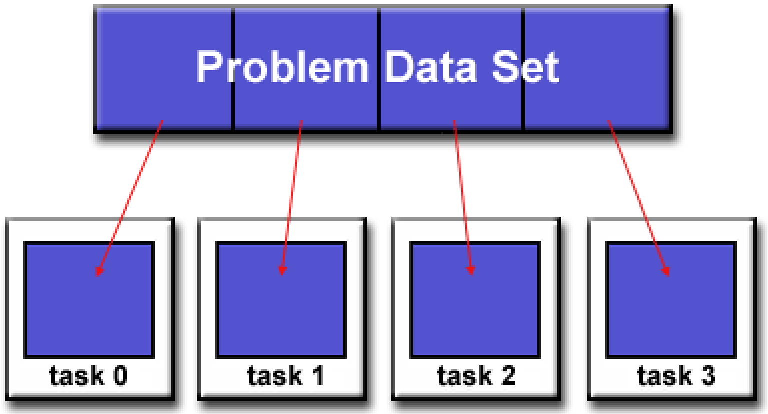

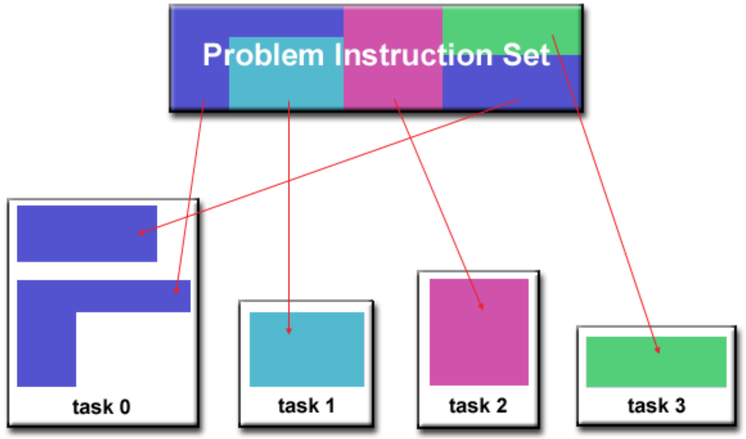

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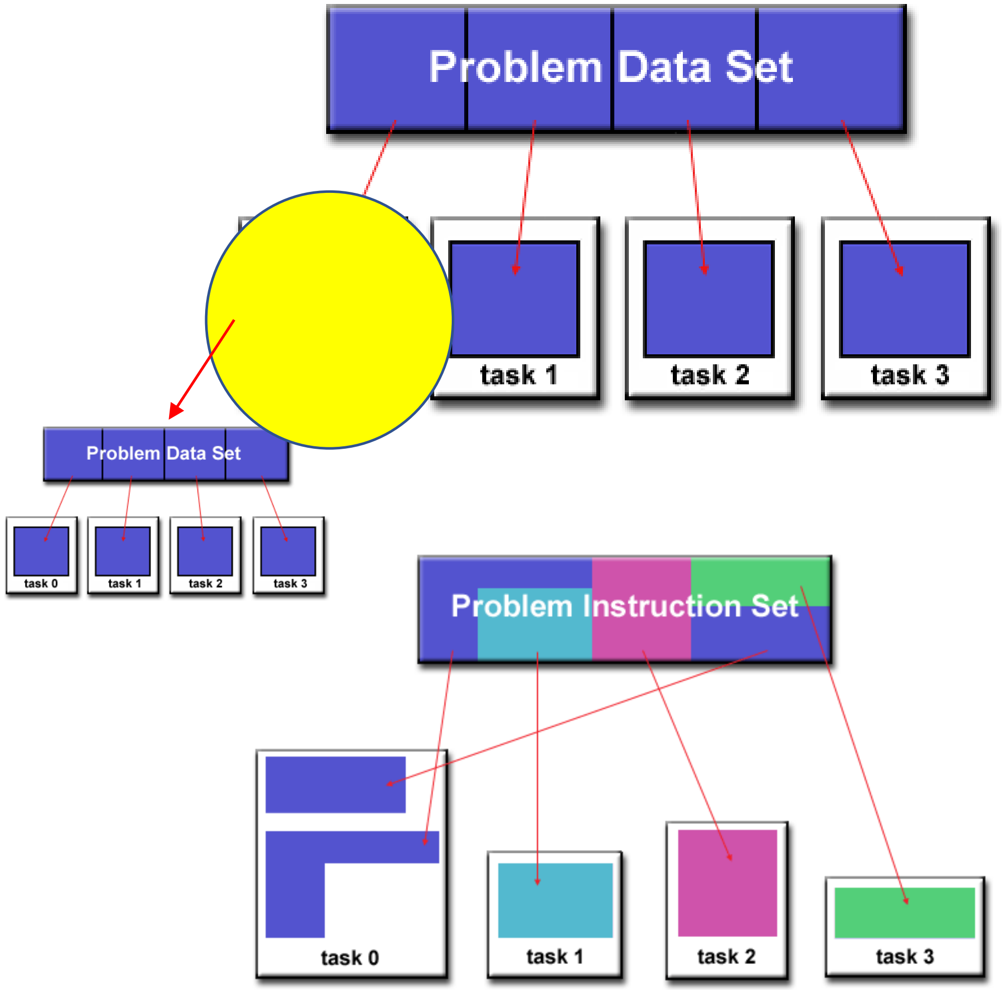

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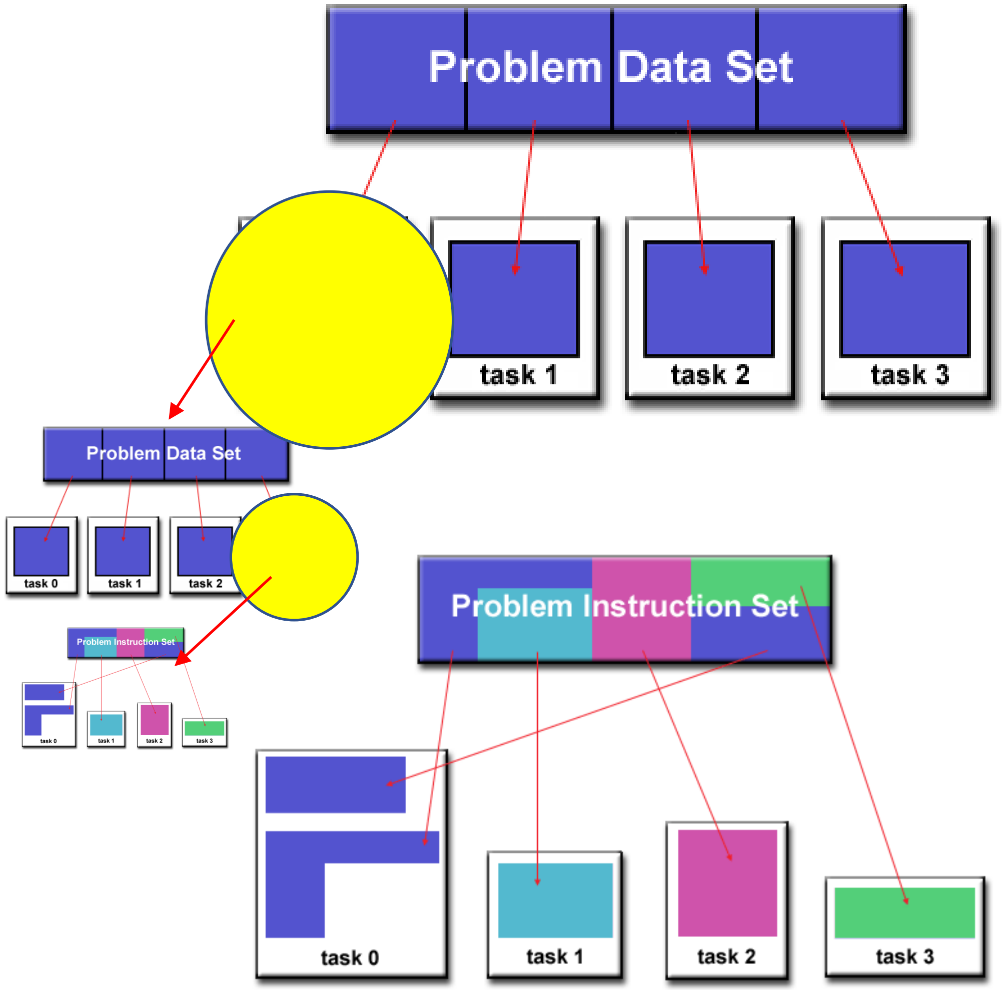

Exercise: Parallelizing Fibonacci

Serial Fibonacci:

```
int fib(int n) {
    if(n<2) {
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    } else {
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Parallel Fibonacci:

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void * fib(void * arg) {
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        pthread_create(&xtid, fib, arg); // n-1
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Pros/Cons?

Challenges:

- Granularity/overheads
- Coupled algorithm, parallel structure
- Each level → more parallelism
- How to balance load?

Cilk

Goal:

Support dynamic, asynchronous, concurrent programs.

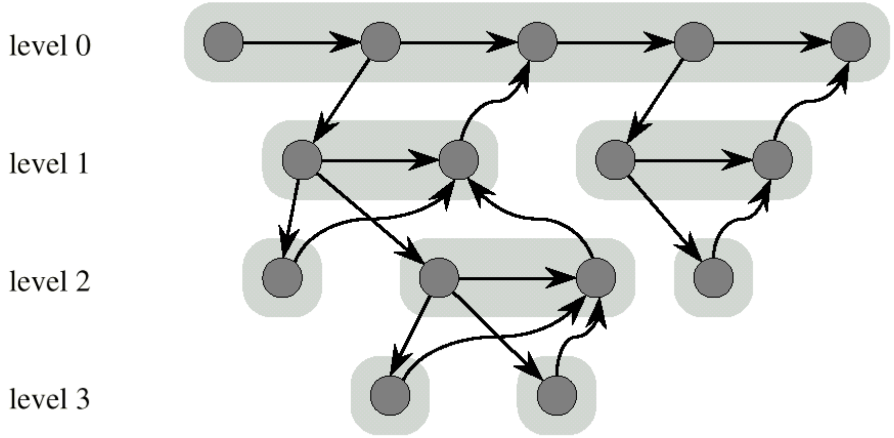
Cilk programmer optimizes:

Total work

Critical path

A Cilk computation:

Dynamic, directed acyclic graph (dag)



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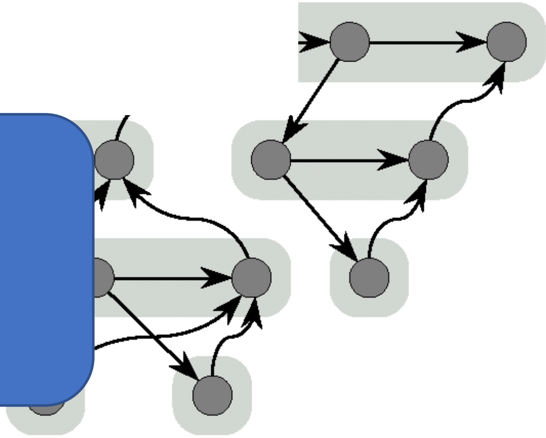

Key idea(s):

- Programmer writes mostly algorithms
- Programmer *identifies parallelism*
- Runtime figures out mapping to machine

Cilk: Nomenclature

Cilk *program* is a set of procedures

A *procedure* is a *sequence* of threads

Cilk *threads* are:

- represented by nodes in the DAG
- **Non-blocking**: run to completion:
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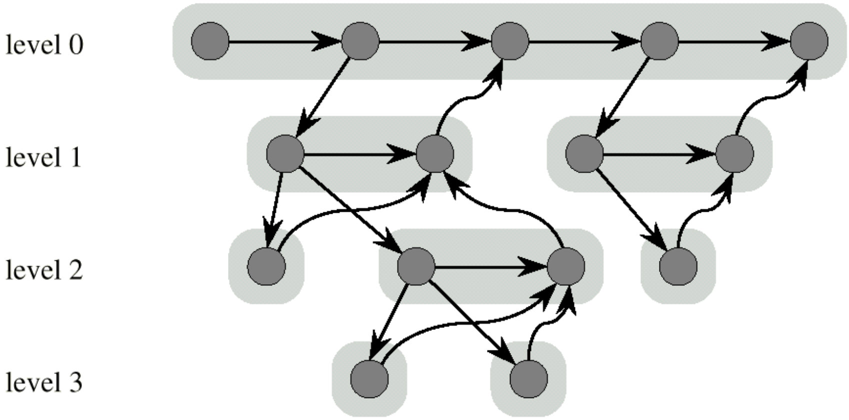

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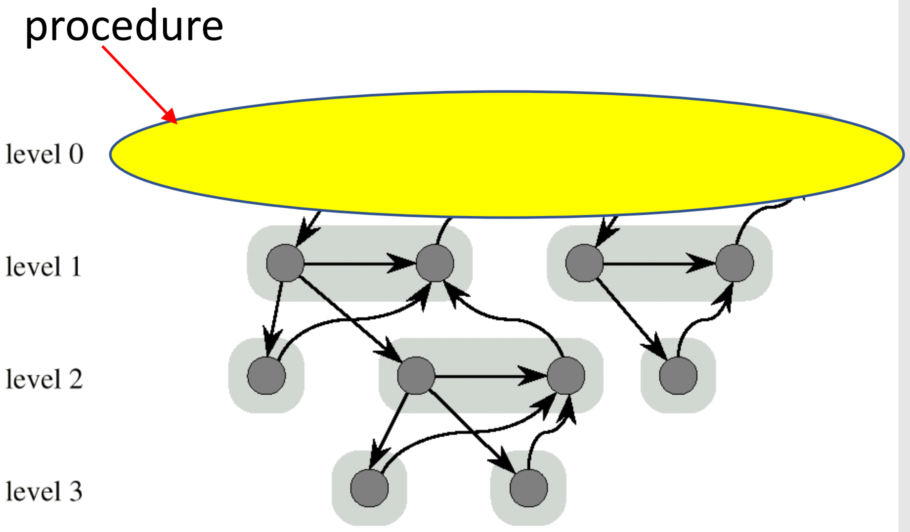

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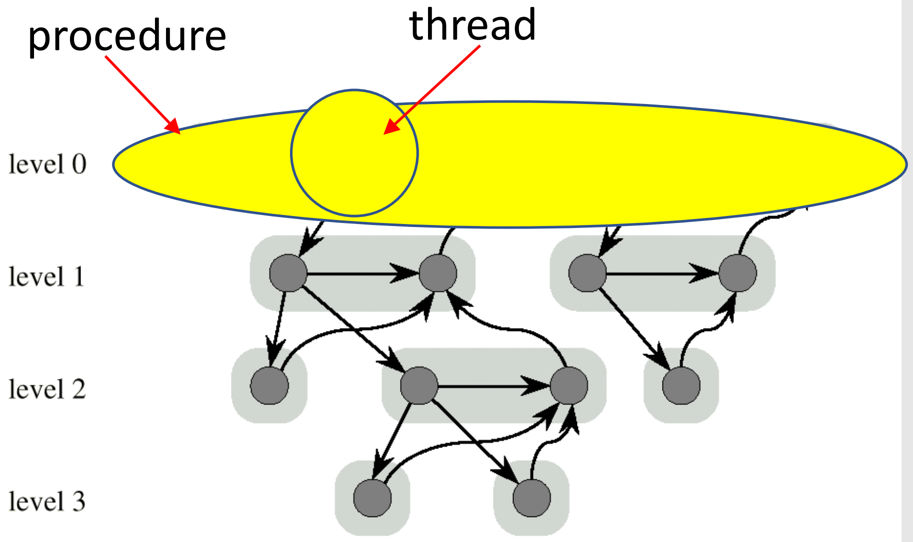

Programming Model

Threads can *spawn* children

- Primary mechanism to create parallel work
- downward edges connect a parent to its children

A child & parent can run concurrently.

- Non-blocking threads ➔ a child cannot return a value to its parent.
- The parent spawns a *successor* that receives values from its children

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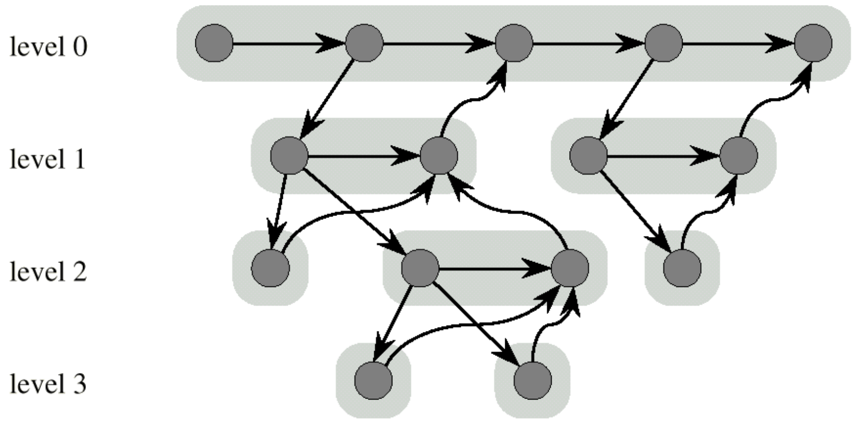

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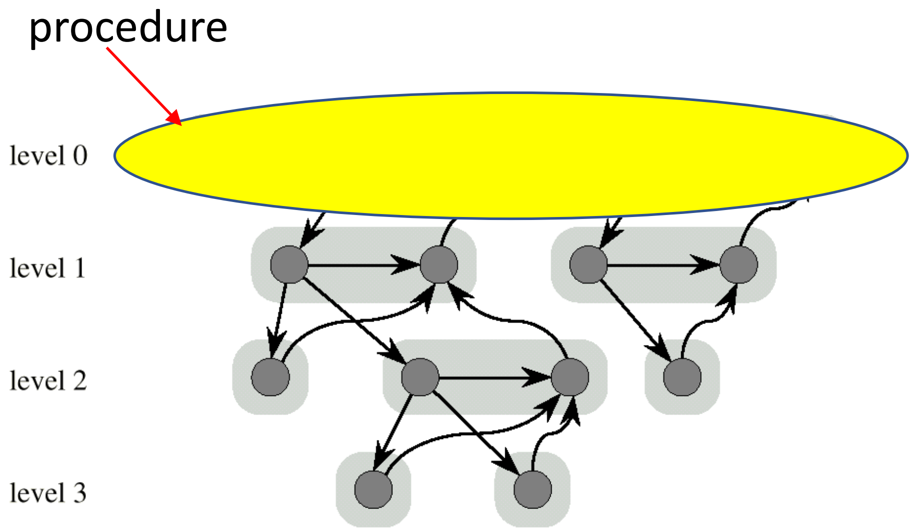

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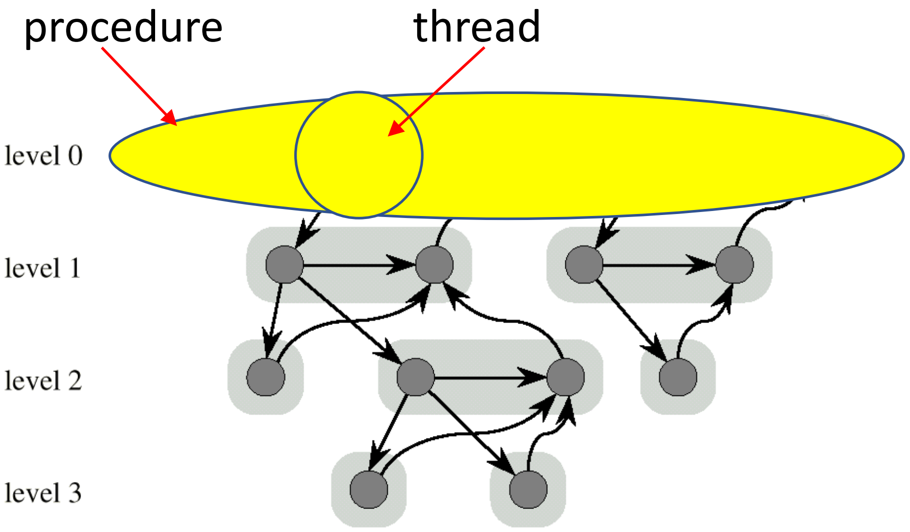

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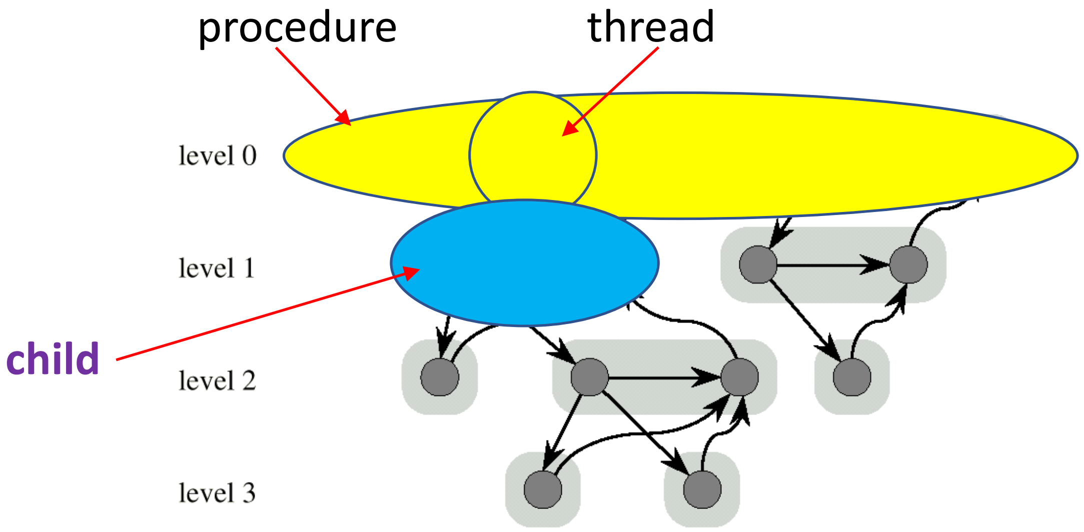

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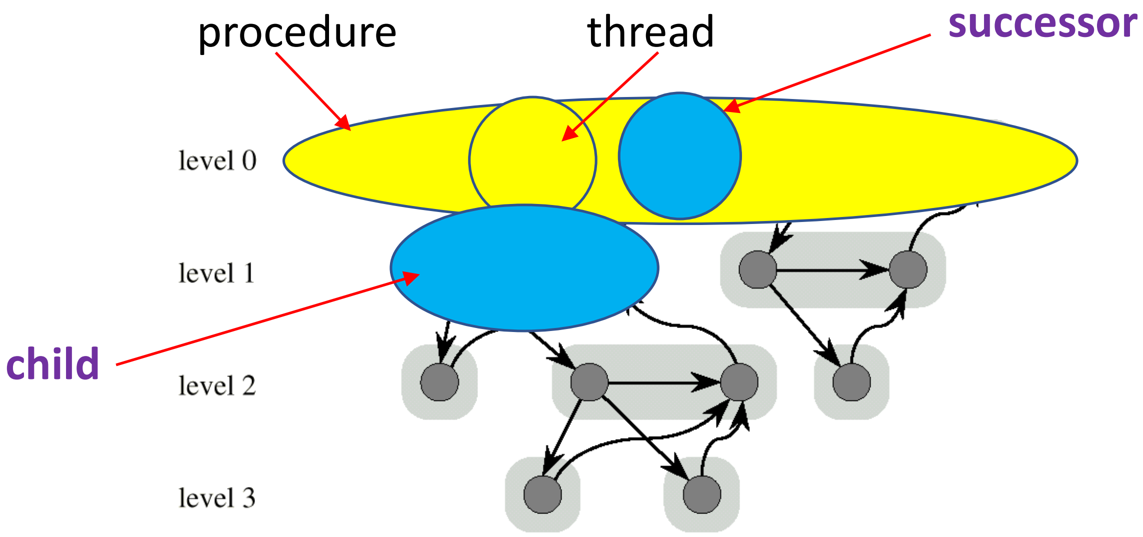


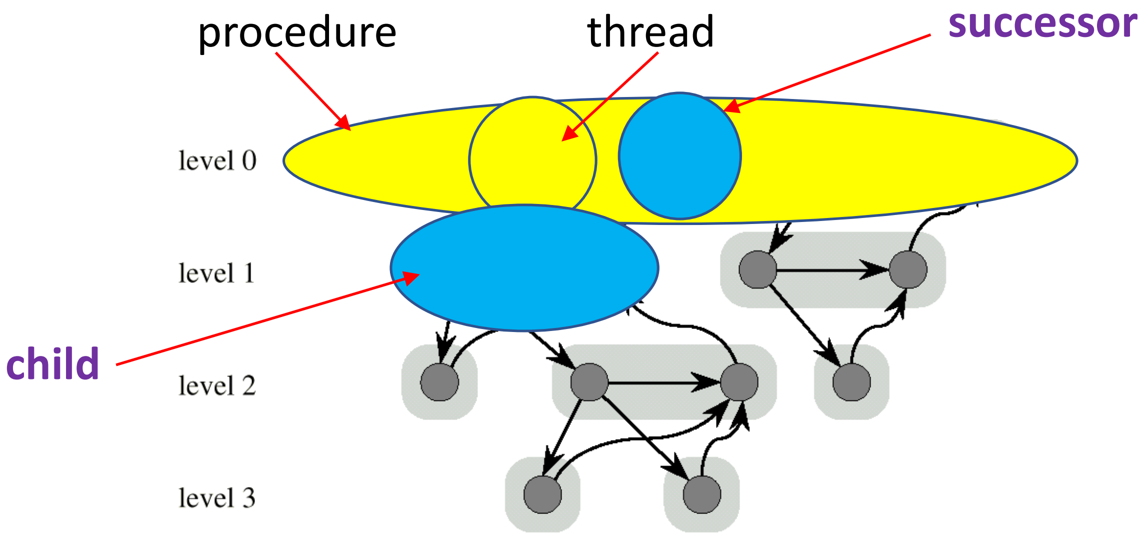
Programming Model

Thread & successor: parts of the same Cilk procedure.

- Connected by horizontal arcs

Children's returned values:

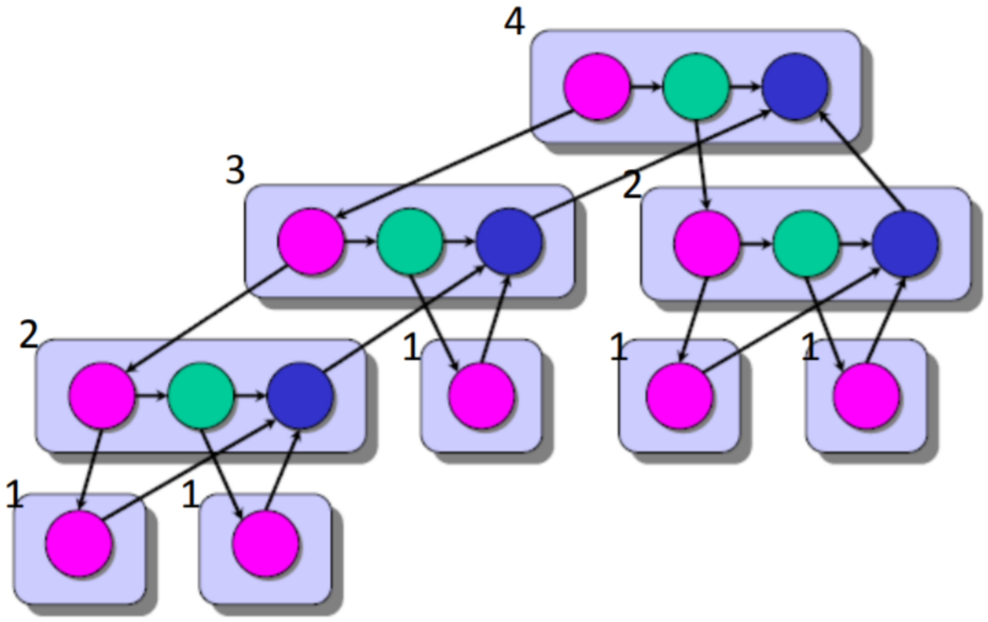
- Received before their successor begins
- They constitute data dependencies.
- Connected by curved arcs



Execution Model

```
cilk fib (int n) {
 if (n < 2) return 1;
   else {
      int rst = 0;
      rst += spawn fib (n-1);
      rst += spawn fib (n-2);
    sync;
     return rst;
  }
}
```

Compute: fib (4)



Source: http://supertech.csail.mit.edu/cilk/lecture-1.pdf

Explicit Continuation Passing

Nonblocking threads ➔ parent cannot block on children's results.

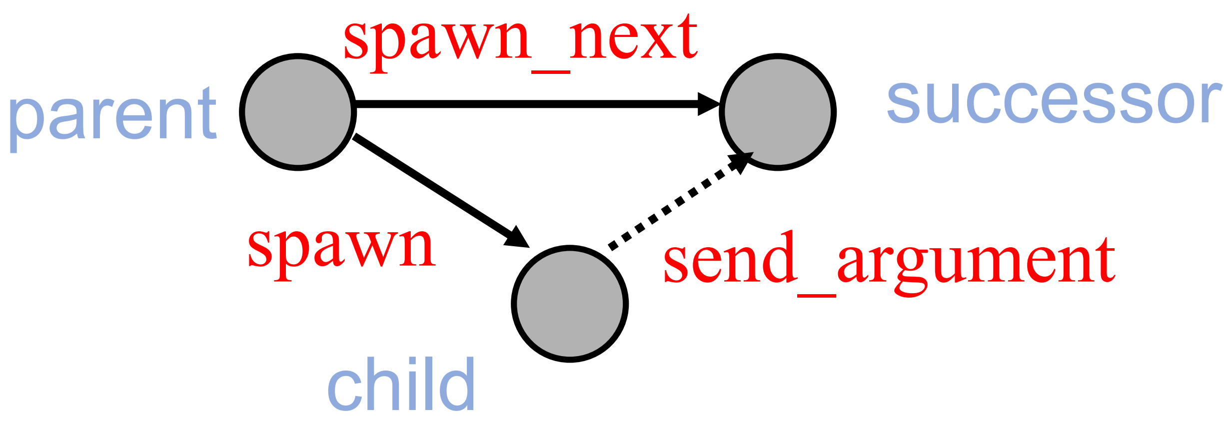
Parent spawns a successor thread.

Called *explicit continuation passing*.

Cilk primitive to *send a value* from a closure to another:

send_argument(k, value)

sends value to the argument slot of a waiting closure specified by continuation k.



Environment: Closures and Continuations

A *closure* is a data structure that has:

a pointer to the C function for T

a slot for each argument

(inputs & continuations)

join counter: # of missing arg values

Closure is ready when join counter == 0.

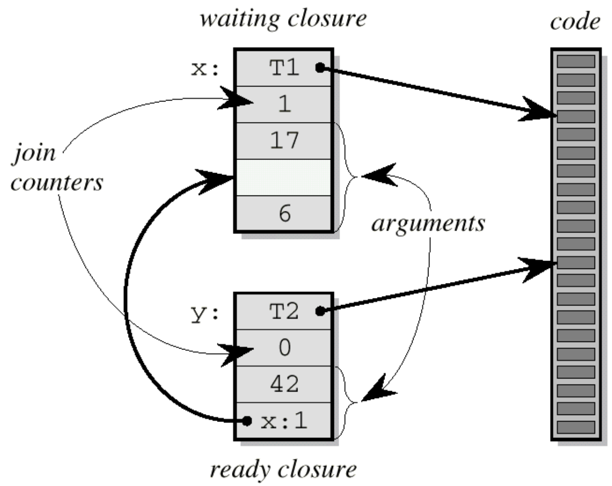
A closure is waiting otherwise.

Closures allocated from a runtime heap

- *Continuation* is a data type,

```
cont int x;
```

- Global reference to an *empty slot of a closure*.
- Implemented as 2 items:
  - pointer to closure; (what thread)
  - int value: slot number. (what input)



Execution Time & Scheduling

Execution time of a Cilk program using P cores **depends on**:

Work (T_1): time for Cilk program with 1 processor to complete.

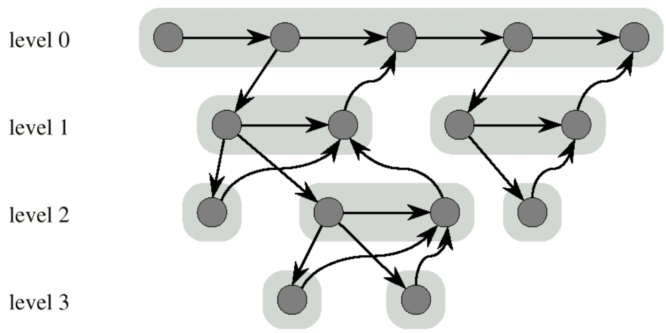
Critical path (T_∞): the time to execute the longest directed path in the DAG.

$T_P >= T_1 / P$

$T_P >= T_\infty$

Parallelism = T_1 / T_∞ **or** *(Work/Depth)*

- Cilk uses run time scheduling: work stealing.
- For "fully strict" programs
  - asymptotic optimality for:
  - space, time, & communication



Nonblocking Threads: Pros, Cons

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Shallow call stack.

Simplify runtime system:

Completed threads leave C runtime stack empty.

Portable runtime implementation

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Con: programmer deals with continuation passing.

Stealing Work: The Ready Deque

Work-stealing:

- Process with no work selects a victim
- Gets shallowest thread in victim's spawn tree.

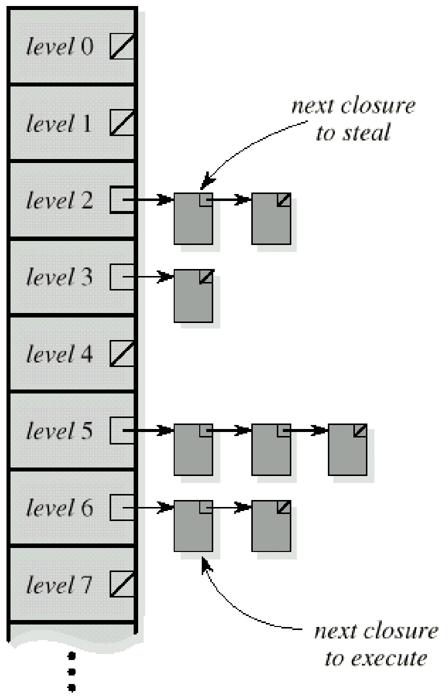
Thieves choose victim processor *randomly*.

Each closure has a level:

- level(child) = level(parent) + 1
- level(successor) = level(parent)

Each processor keeps a ready deque:

- Contains ready closures
- The **L**th element contains the list of all ready closures whose level is **L**.



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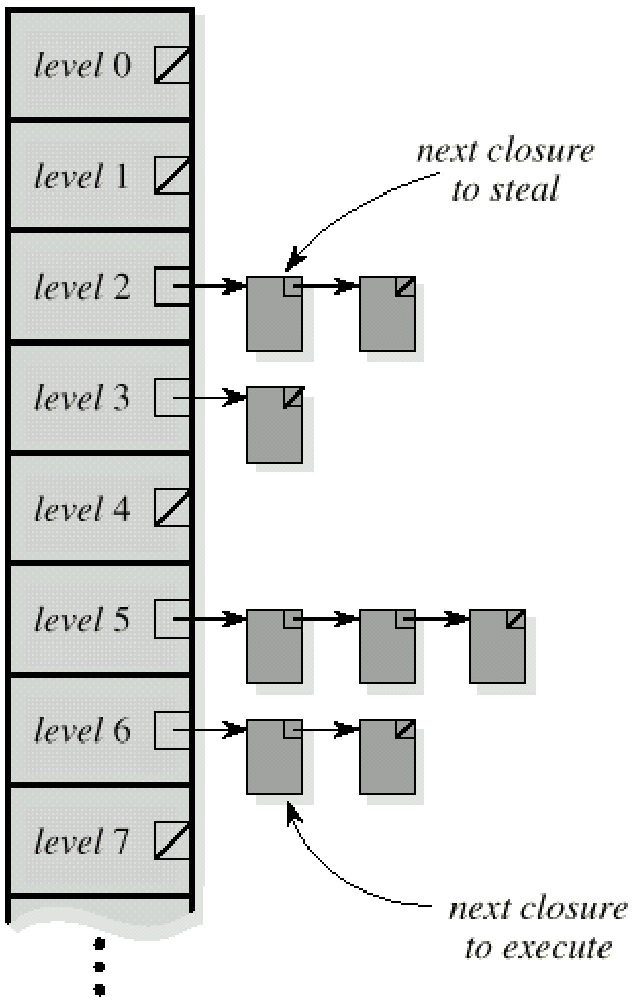

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take deepest thread

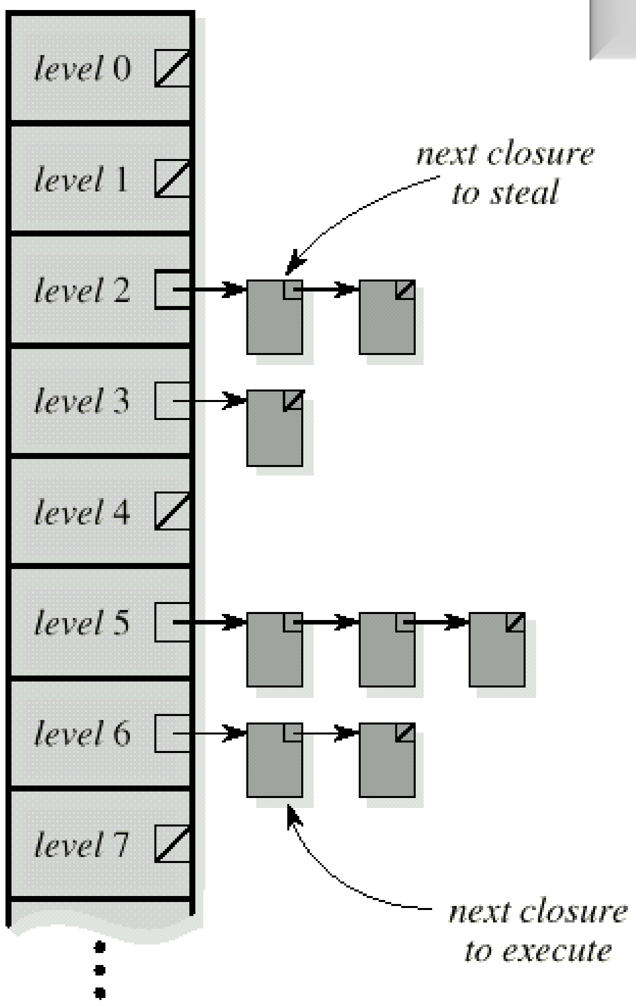
else

steal shallowest thread from

readyDeque of *randomly*

selected victim

Ready Deque



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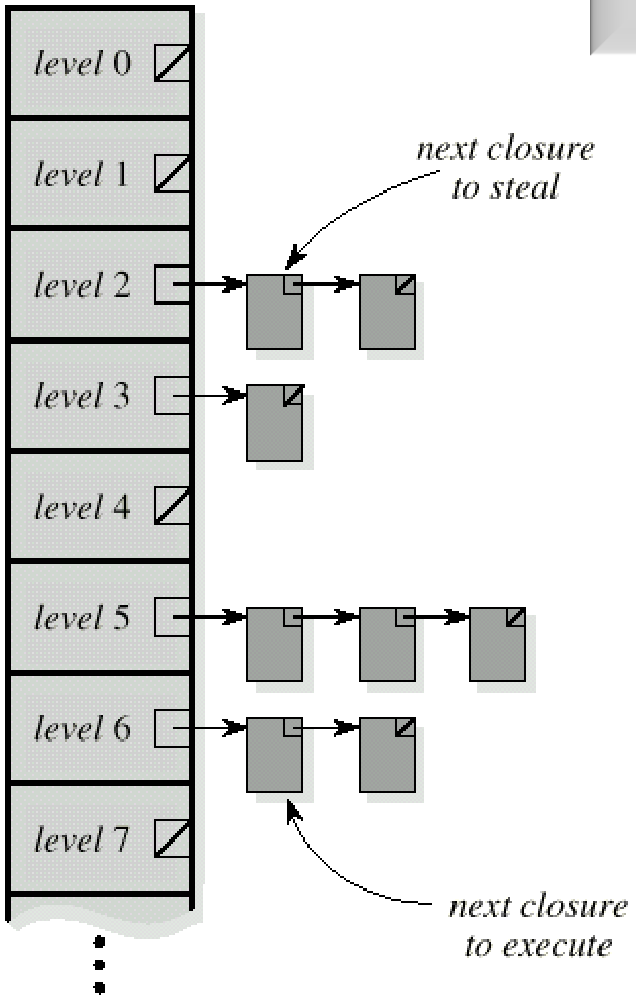

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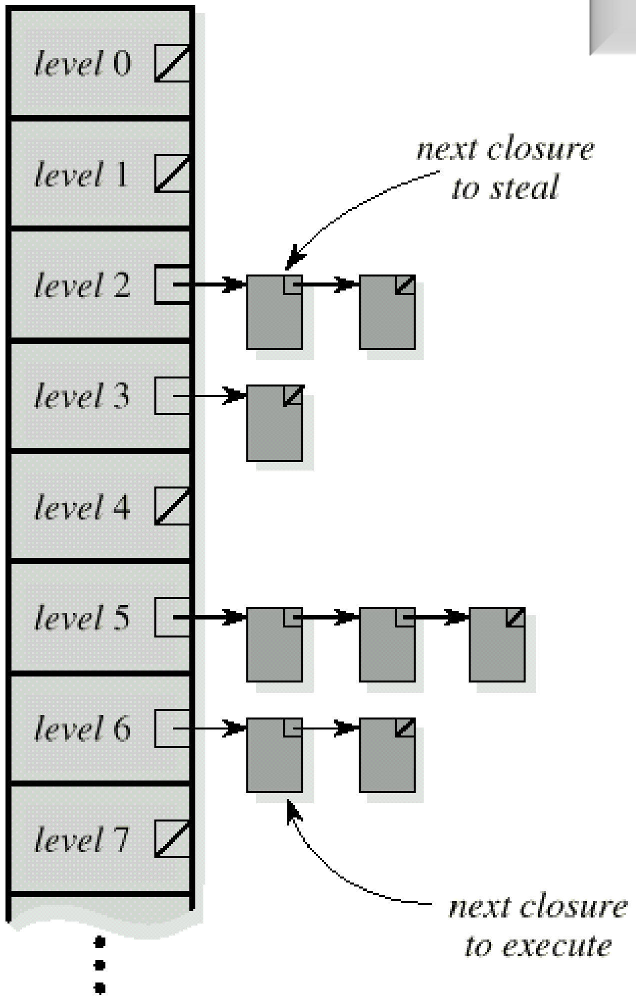

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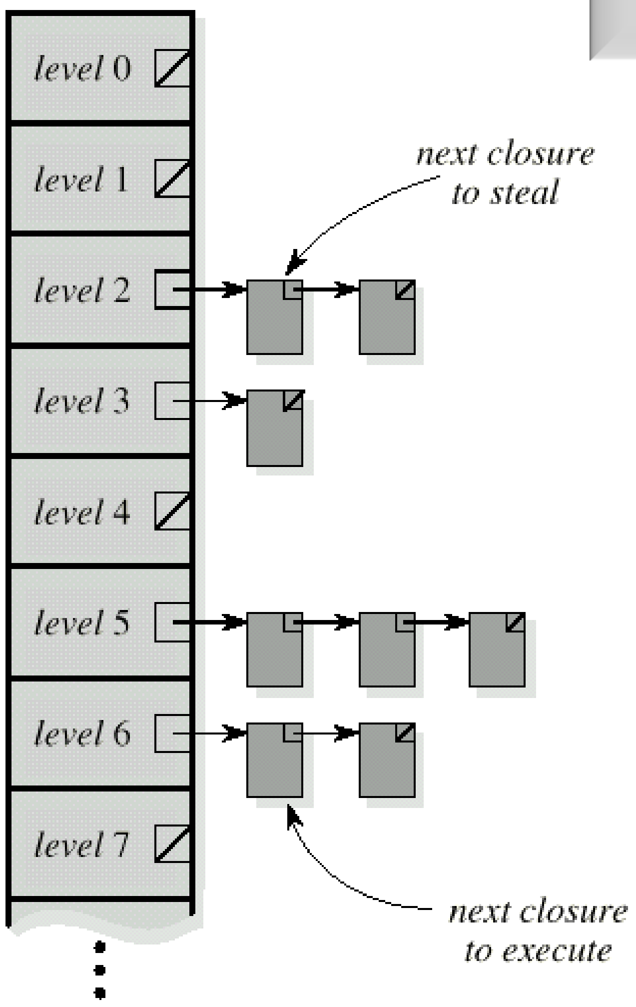
Shallow threads *more likely to be* on critical path.



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Cilk is an extension of C

Cilk programs are:

- preprocessed to C
- linked with a runtime library

- Declaring a thread:

thread T (<args>) { <stmts> }

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Concluding Remarks

Cilk illustrates a number of important (recurring) ideas:

- DAG-based parallel execution model
- Critical-path heuristic for available parallelism
- Continuation passing
- Work-stealing scheduling

Discussion/Food For Thought:

- Is continuation passing style (CPS) difficult?
- Why/why not?

Title

Content