Speculative Parallelism in Cilk++

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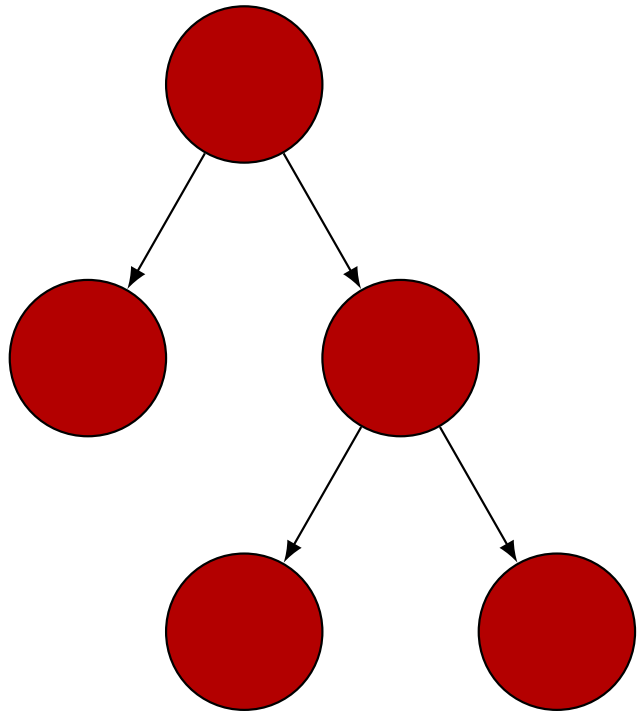
Parallelizing Embarrassingly Parallel Problems

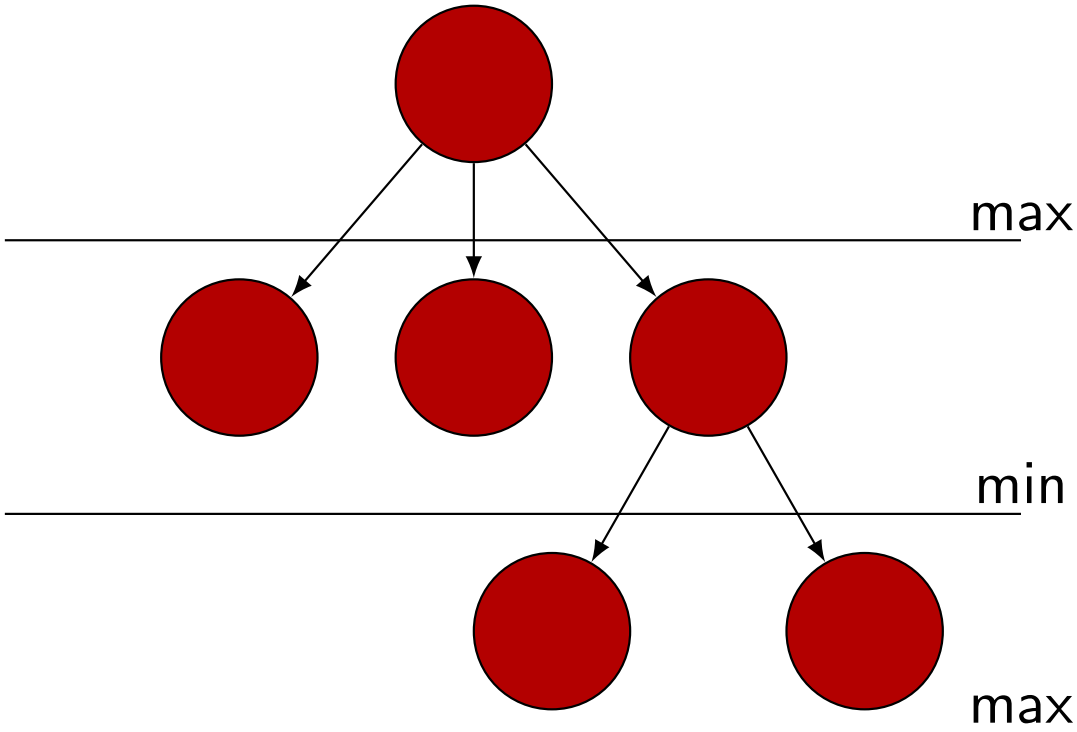
- Lots of search algorithms are *embarrassingly parallel*.
  - Search down all the paths of a tree.
  - Search multiple disjoint branches in parallel.
    - No communcation overhead.
    - Very little memory contention.
  - Since we often only need a single answer, we can stop once we've found any solution.
- Cannonical algorithms are in game-search, minimax and α-β pruning.

2 Player Game Trees

- Nodes represent game states.
- Edges represent transitions between states.
- Leaf states are scored by a heuristic.
- Goal is to maximize the heuristic against an adversary.



Parallelizing MiniMax



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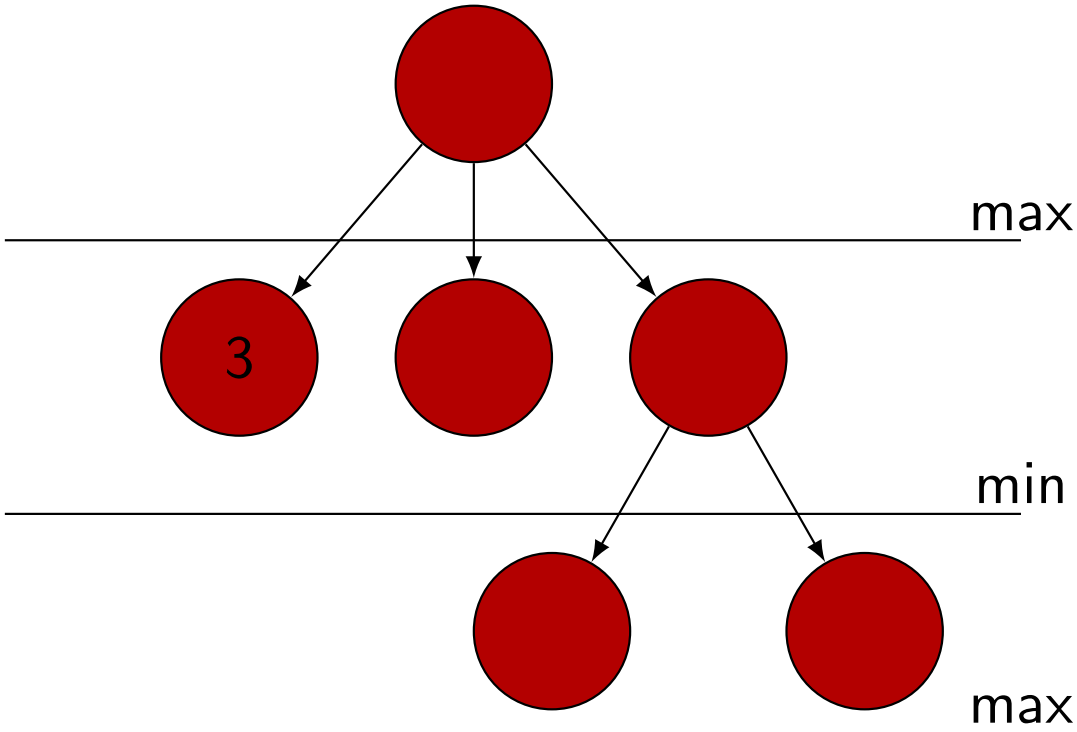

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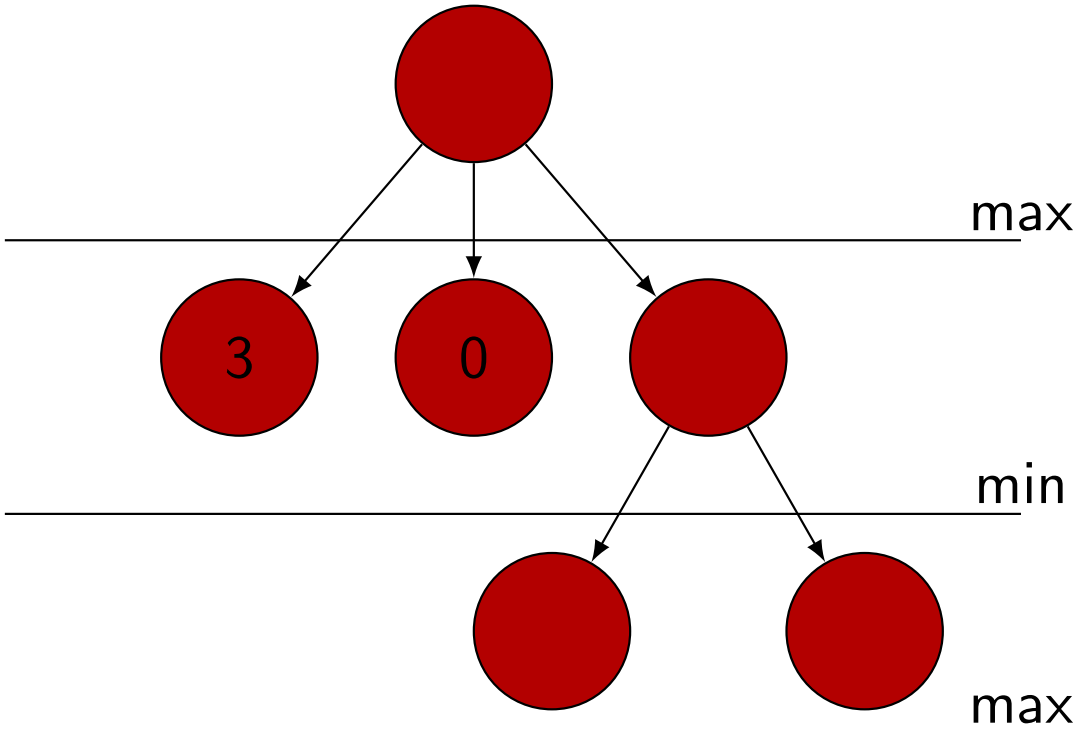

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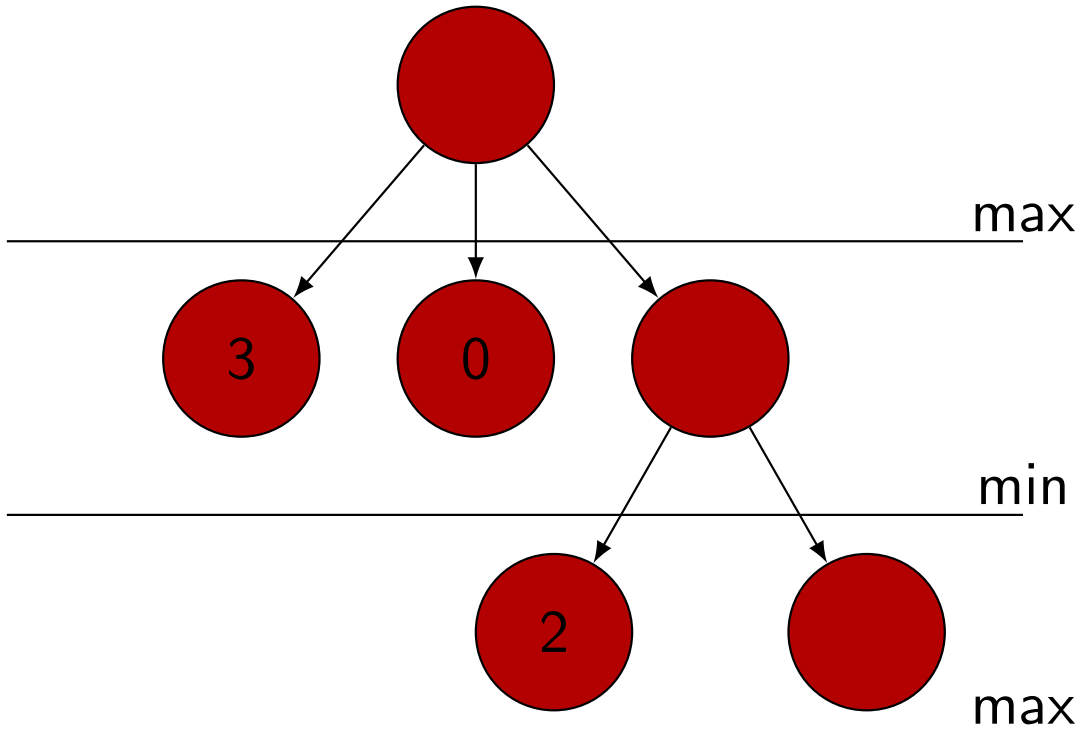

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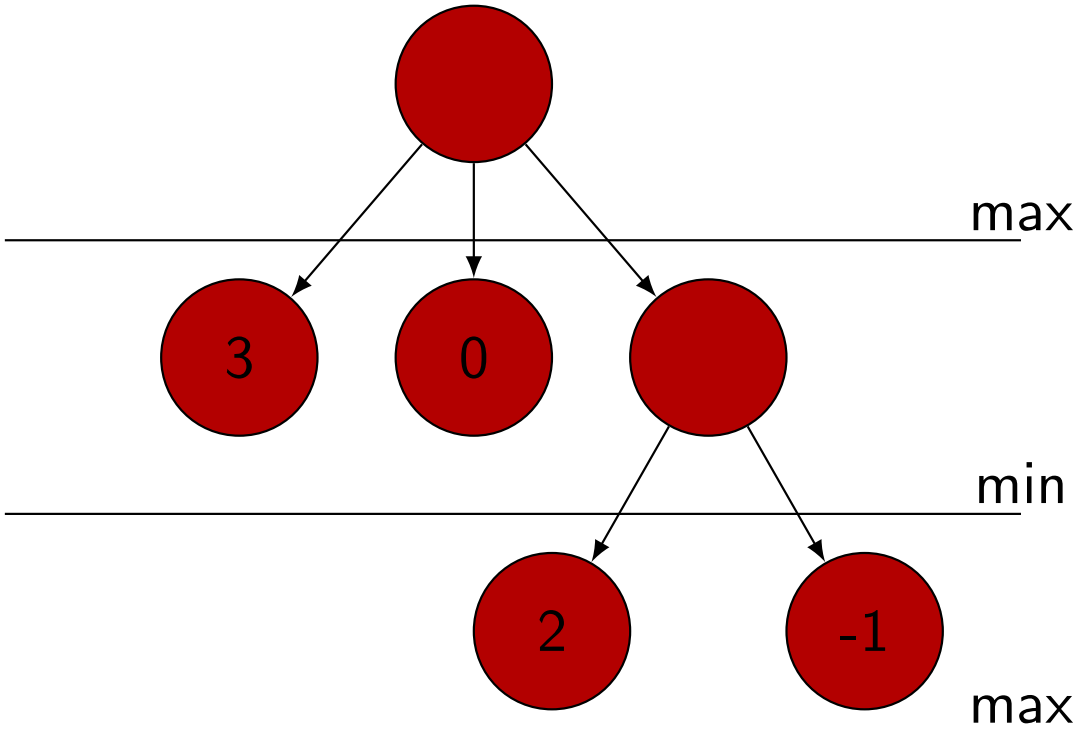

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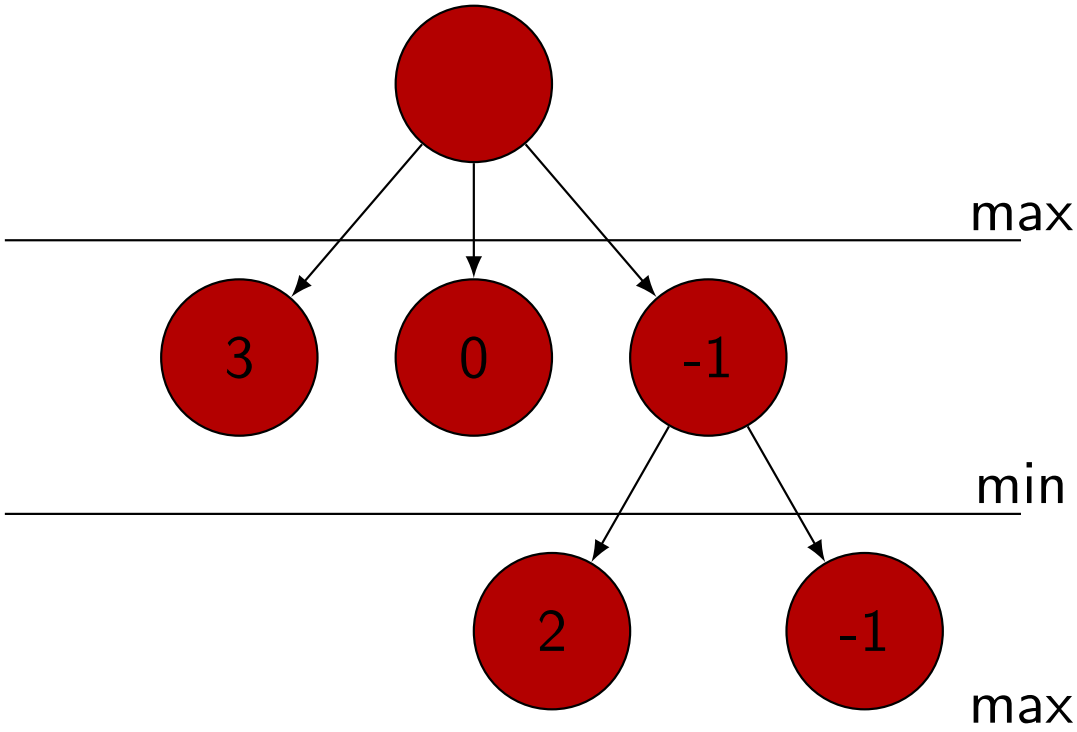

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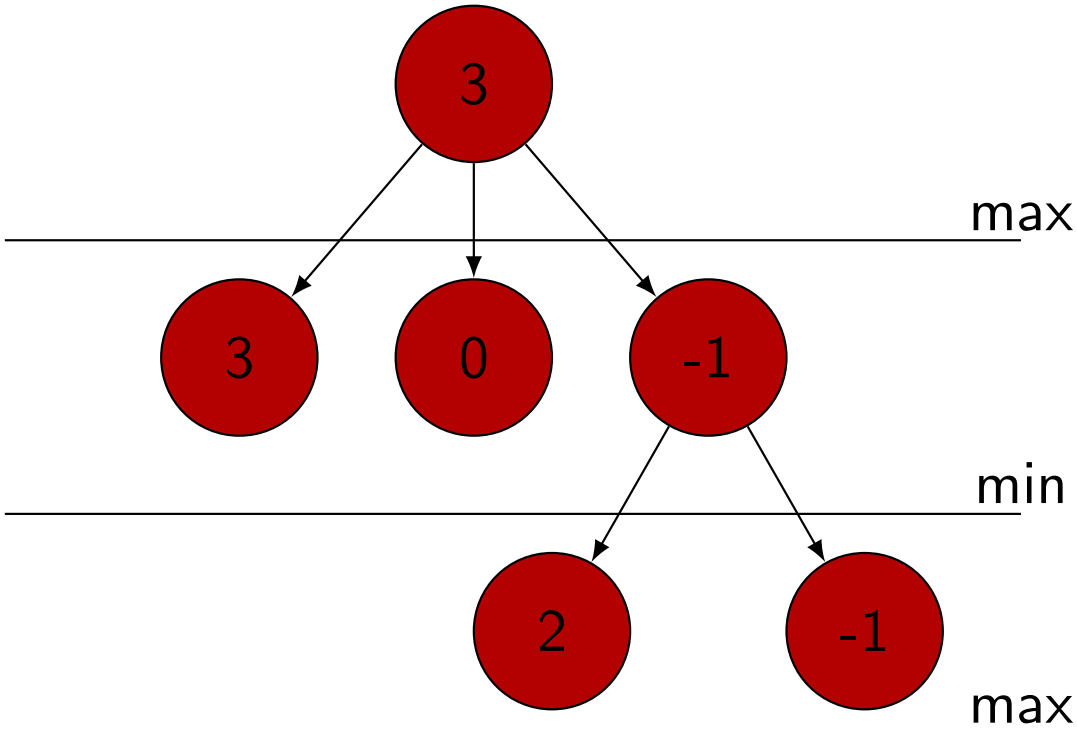

Improving MiniMax

- MiniMax exhaustively searches the game tree to a certain depth (iterative deepening).
- Not efficient for most games due to large branching factor.
  - Can't search deep enough for the computer to be smart.
- **Intuition** Keep track of the range of feasible scores and prune branches that fall outside the range.

α-β Pruning

- Keep additional information with each game node: α and β.
- α is the lower bound on the player's score.
- β is the upper bound on the player's score.
- This pruning allows us to search twice as deep on average.

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Let's see an example...

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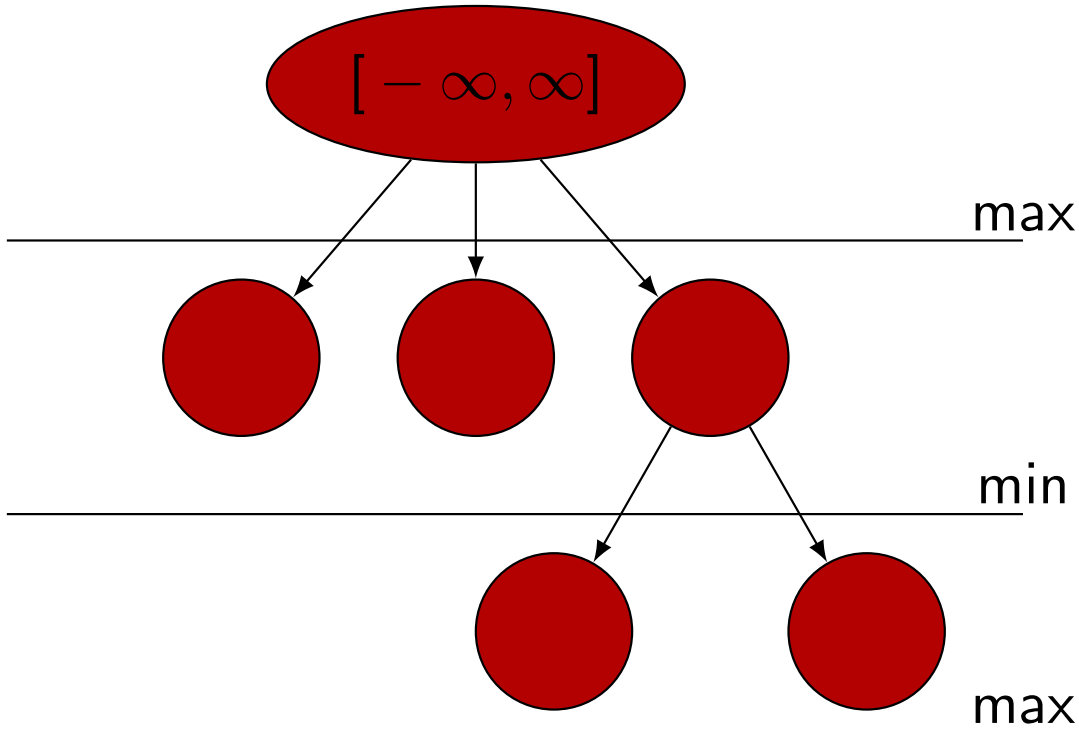

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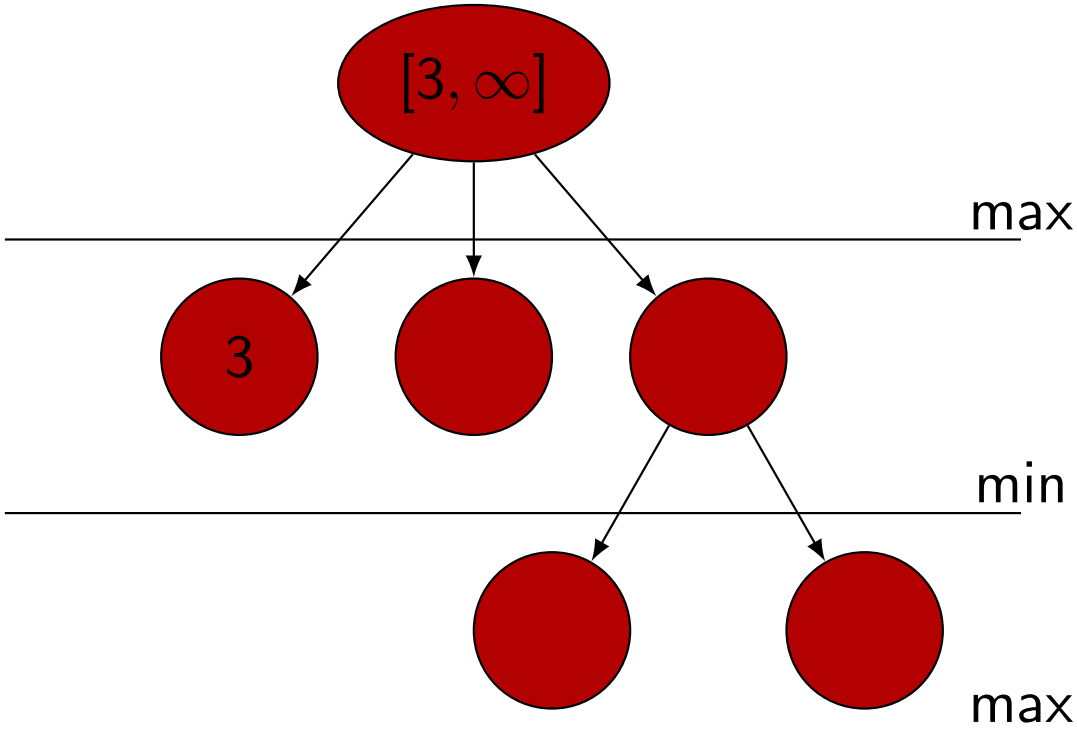

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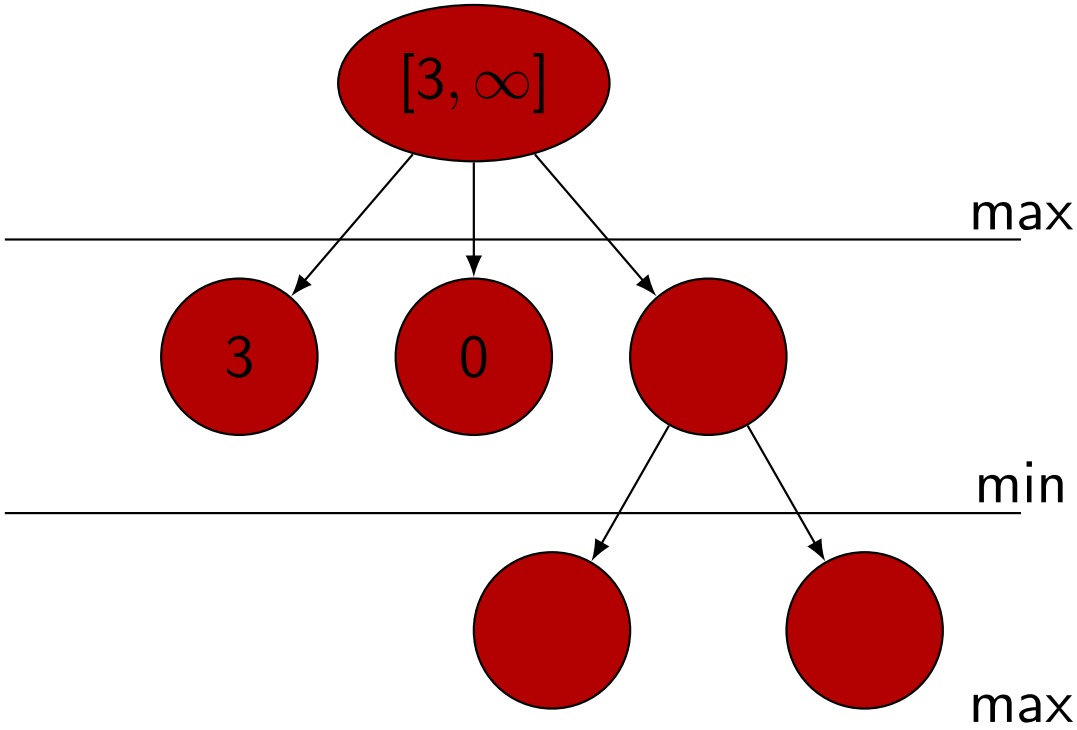

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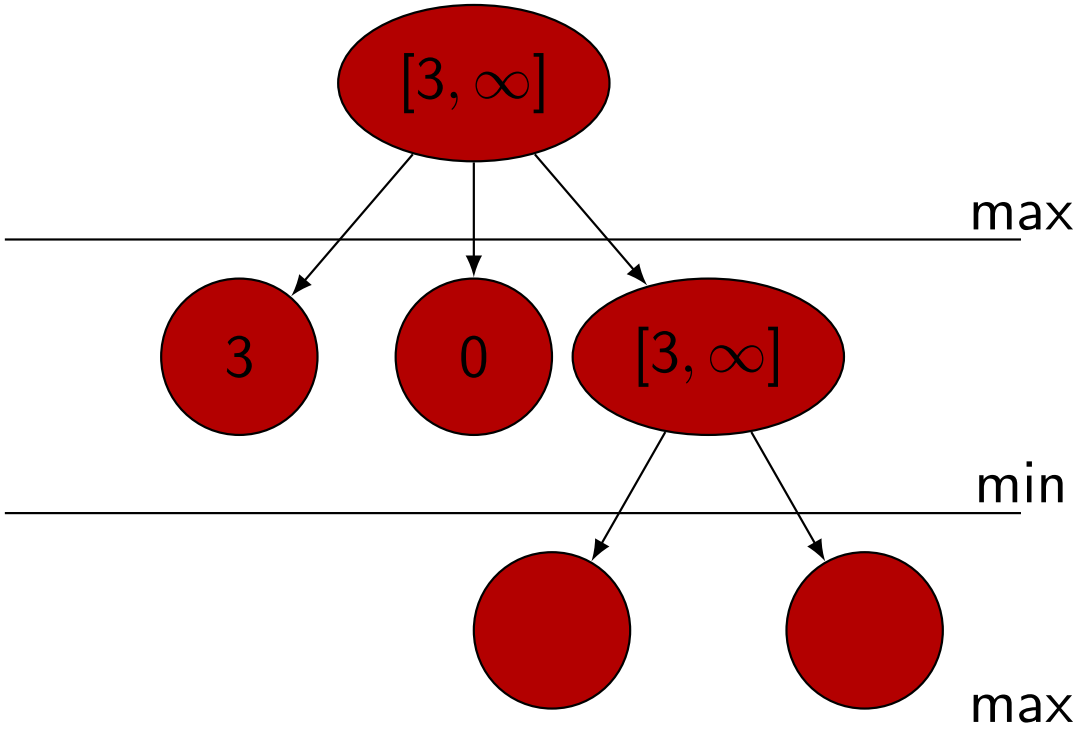

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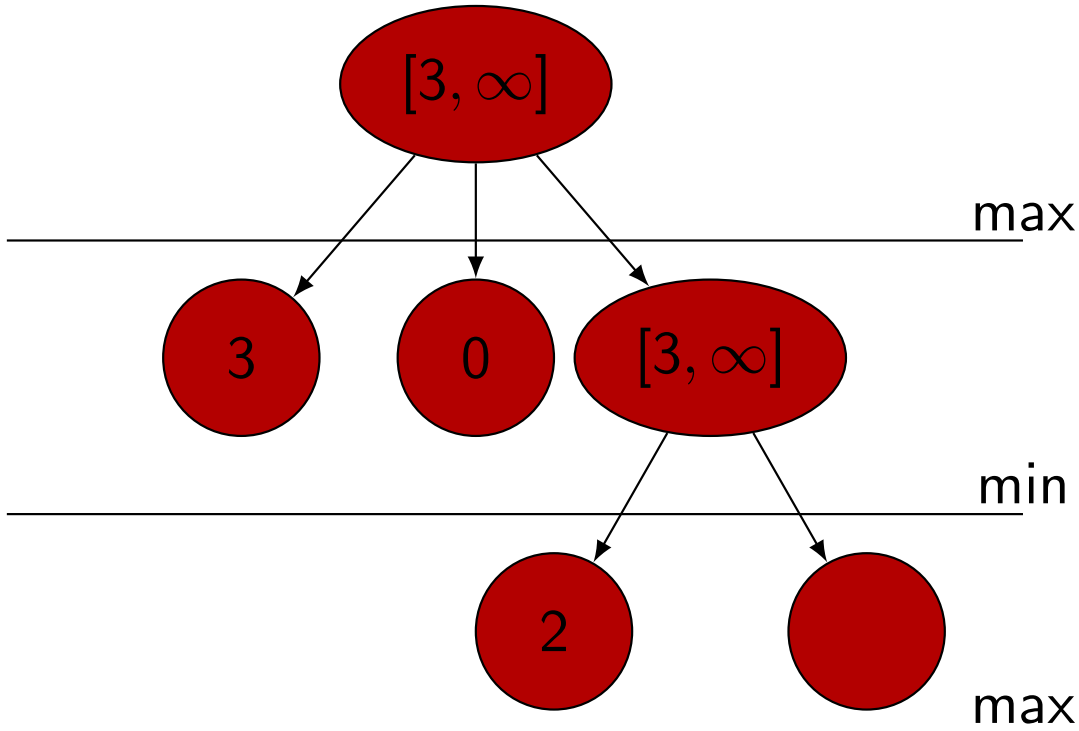

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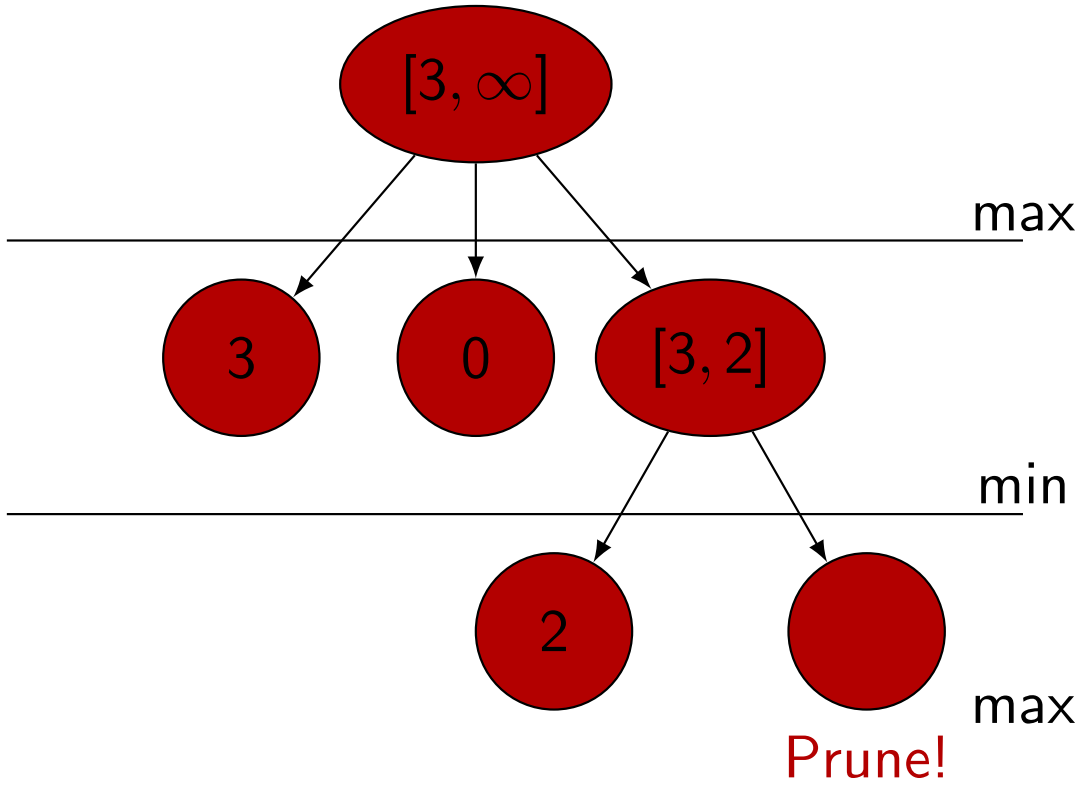

Outline

1. A Recipe for Speculation
   - Porting the Example
   - Implementing `abort`
2. Evaluation
   - Performance
   - Complexity Porting Old Code
3. Conclusions

A Recipe for Speculation

- When we speculate, we don't want to have to commit to something finishing.
  - Need a way to abort currently running computations that we don't need anymore.
  - For consistency, we'd like to be able to abort computations that are speculating.
- We also need a way to combine the results.
  - Reducers would work for this, but they will need to be able to call abort.
  - Older versions of `cilk` had another mechanism for this.

Speculation in Cilk5

- Speculation is just based on `spawn`.
- Combining results done through `inlets`.
  - `inlets` are functions that merge results together (similar to reducers).
  - `inlets` can also make the choice to abort computations.

Let's look at a simple example.

Simple Example: Native `abort` & Inlets

- Imagine you have two computations that should yield the same result, but one could take significantly longer to compute.

Simple Example: Native abort & Inlets

- Imagine you have two computations that should yield the same result, but one could take significantly longer to compute.
  - Speculatively execute both and abort when the first finishes.

```
int long_computation_1(void* args);
int long_computation_2(void* args);

int first(void* args1, void* args2) {
  int x;
  inlet void reduce(int r) {
    x = r;
    abort;
  }
  reduce(cilk_spawn long_computation_1(args1));
  reduce(cilk_spawn long_computation_2(args2));
  cilk_sync;
  return x;
}
```

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- No support for `abort` or `inlet` in `cilk++`.

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Handling `inlets`

- Inlets are local functions that merge the result of `spawned` computations.
  - Serve a similar purpose to reducers, but a little more general.
  - Get access to the parent function's stack frame.
- **Semantics**
  - `inlets` are locally serial, i.e. all of the `inlets` for a particular stack frame will run serially.
  - The order of executing them is non-deterministic, implementation based on the amount of time that the computations take.

Handling inlets

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```

Handling `inlets` – via Translation

- Translate `inlets` into continuations.
  - Not a particularly painful translation.
  - It can be annoying to work with continuations in C code.
  - Ideally this would be a compilation step.
- Mostly mechanical translation preserves semantics
  - Depending on how they are used, it might be more efficient to use reducers.

cilk5 Code

```
int f_1(void* args);
int f_2(void* args);

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}
```

Translated *cilk++* Code

```
struct InletEnv { cilk::mutex m; int x; };

int f_1(void* args, int(*cont)(int, InletEnv*), InletEnv* env);
int f_2(void* args, int(*cont)(int, InletEnv*), InletEnv* env);

int first_inlet(int result, InletEnv* env) {
  env->m.lock();     // Serial execution
  env->x = result;
  abort;
  env->m.unlock();   // Serial execution
}

int first(void* args1, void* args2) {
  InletEnv env;
  cilk_spawn f_1(args1, first_inlet, env);
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  cilk_sync;
  return env.x;
}
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int first_inlet(int result, InletEnv* env) {
  env->m.lock();     // Serial execution
  env->x = result;
  abort;                    Still need to handle abort
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abort Features

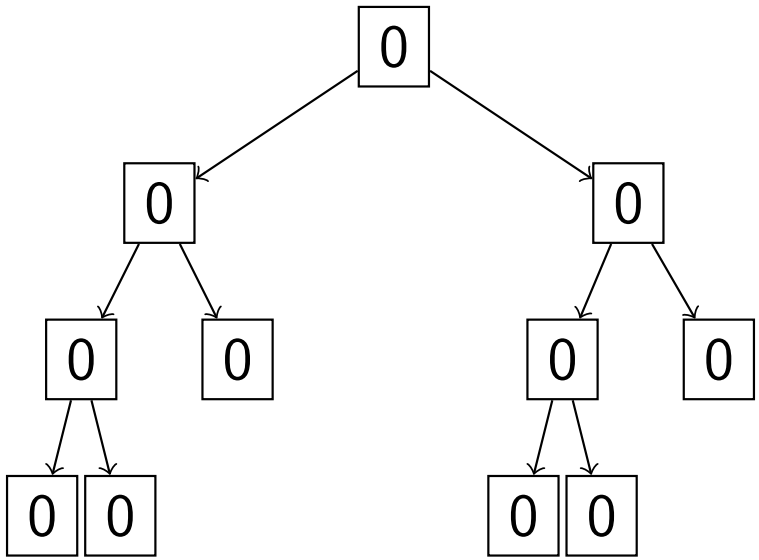
- We saw a notion of global abort in Lab 5.
  - When you abort, you abort everything, completely done.
- This is not compositional.

Compositionality

Compositionality requires the ability to abort speculating computations. Need an abort hierarchy.

Hierarchical abort

- Abort any subtree of the computation without affecting the rest of the computations.



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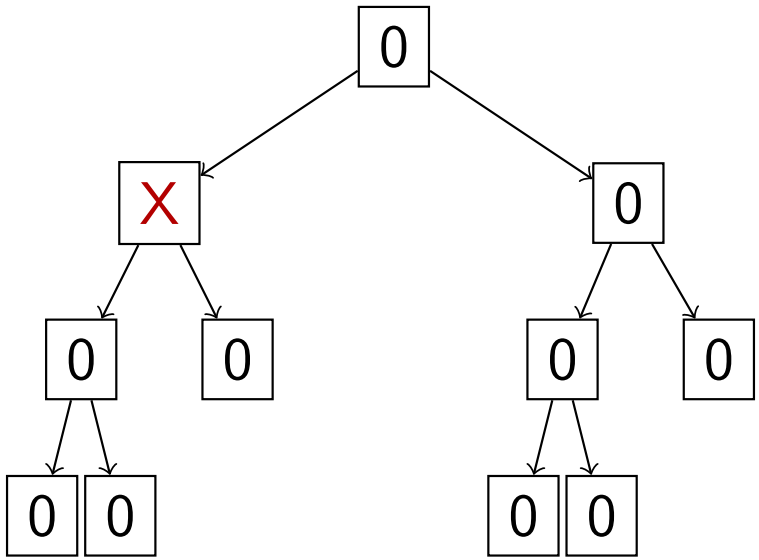

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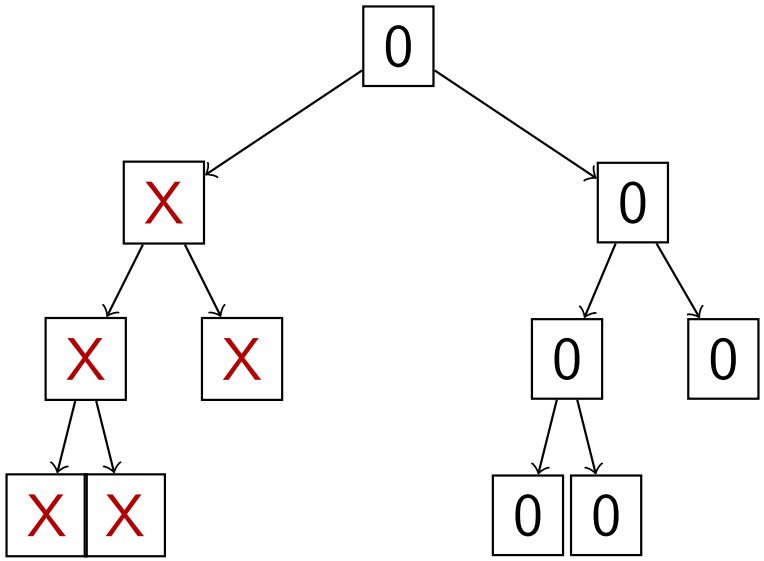
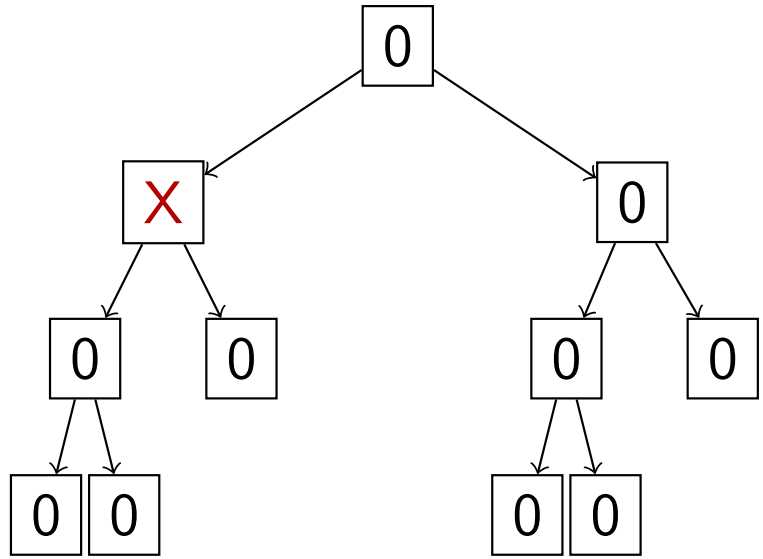


User-Implemented abort

- Implement using polling...



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- Two possible implementations:
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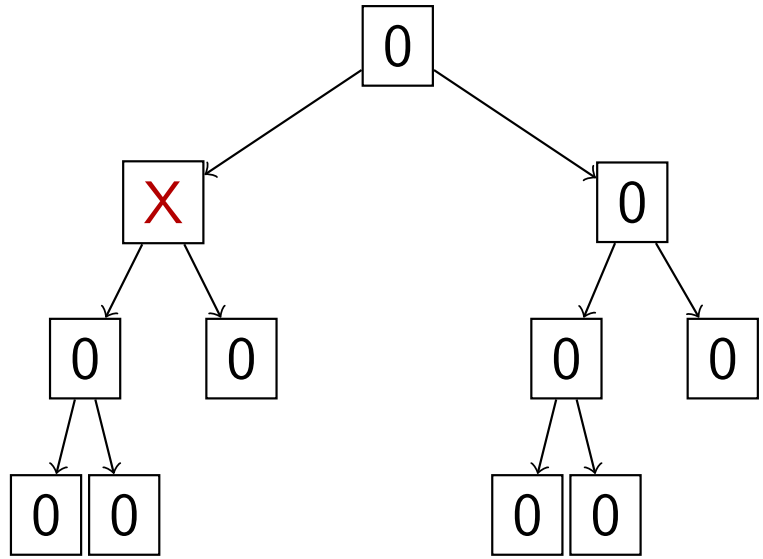

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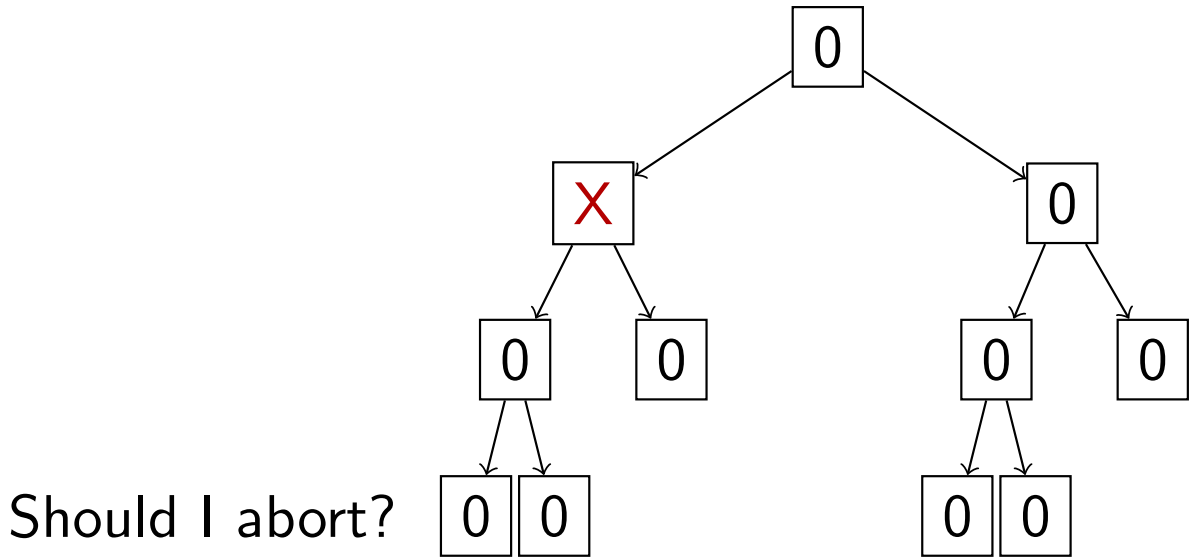

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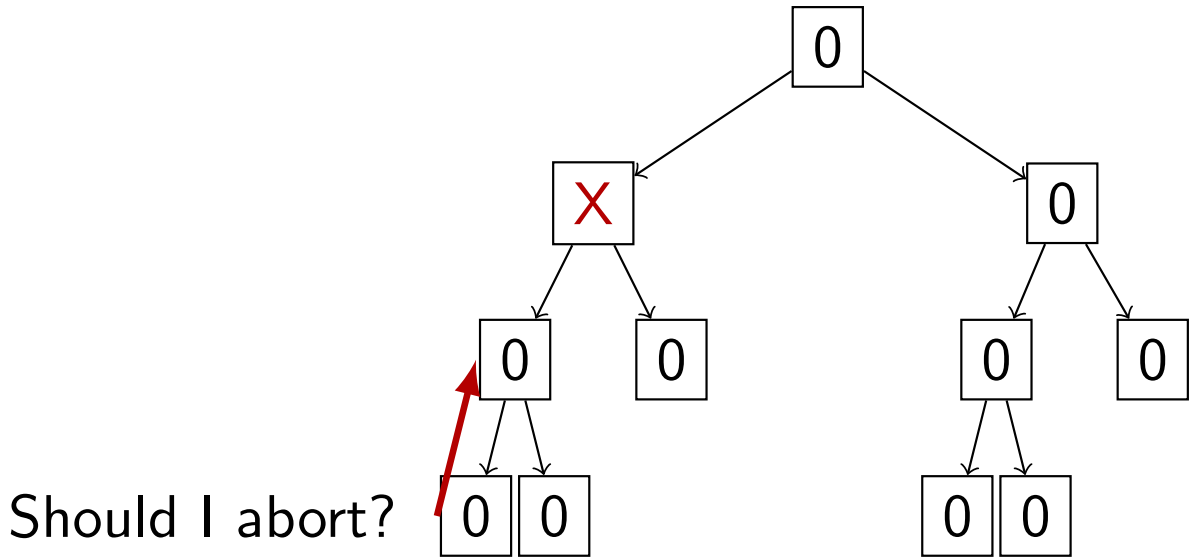

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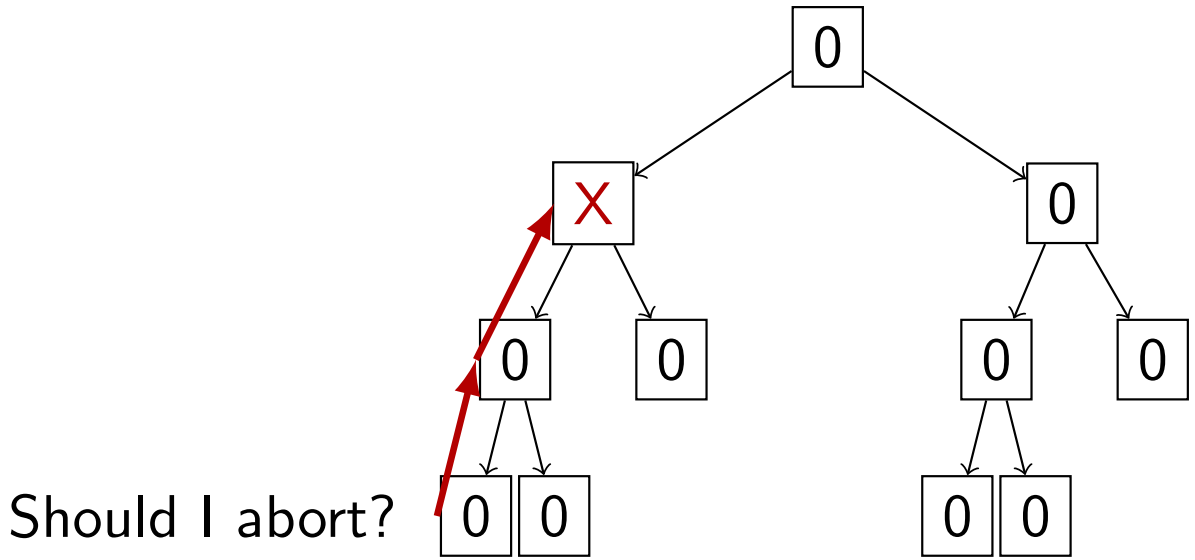

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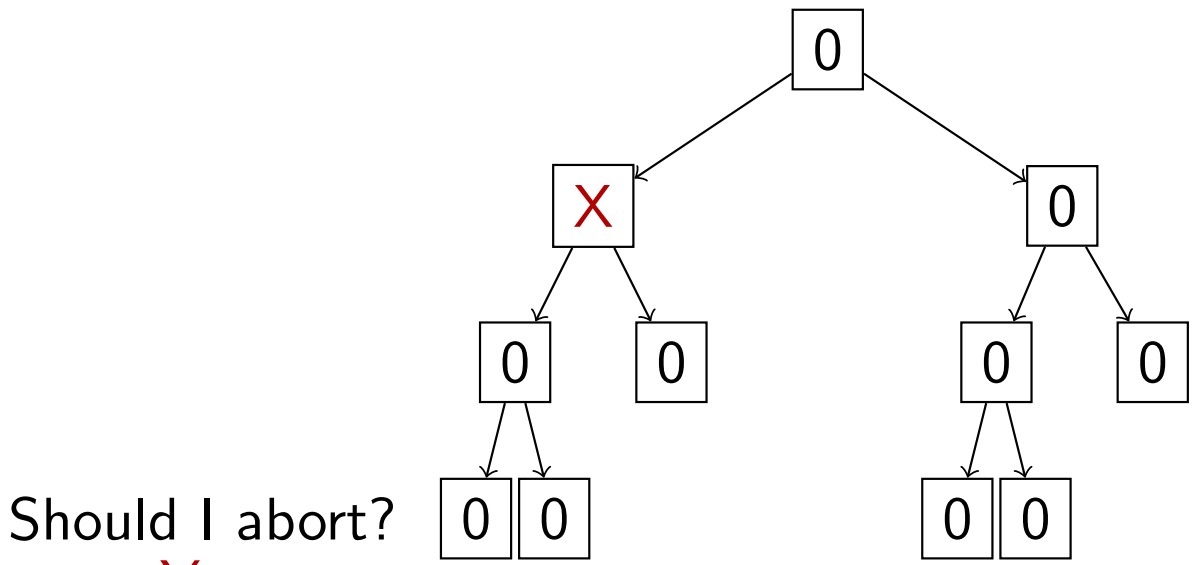

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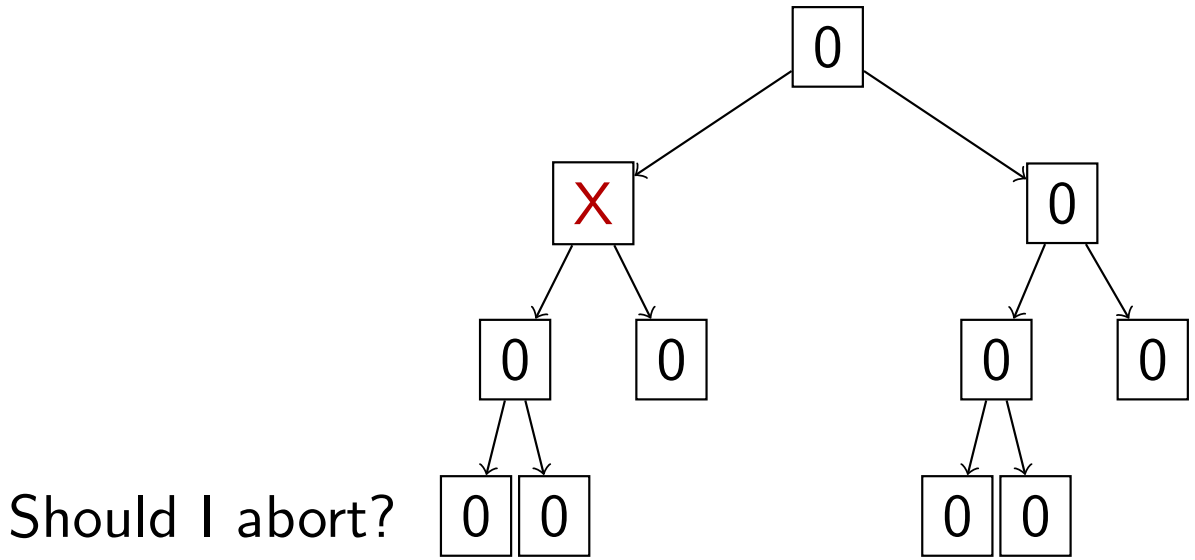

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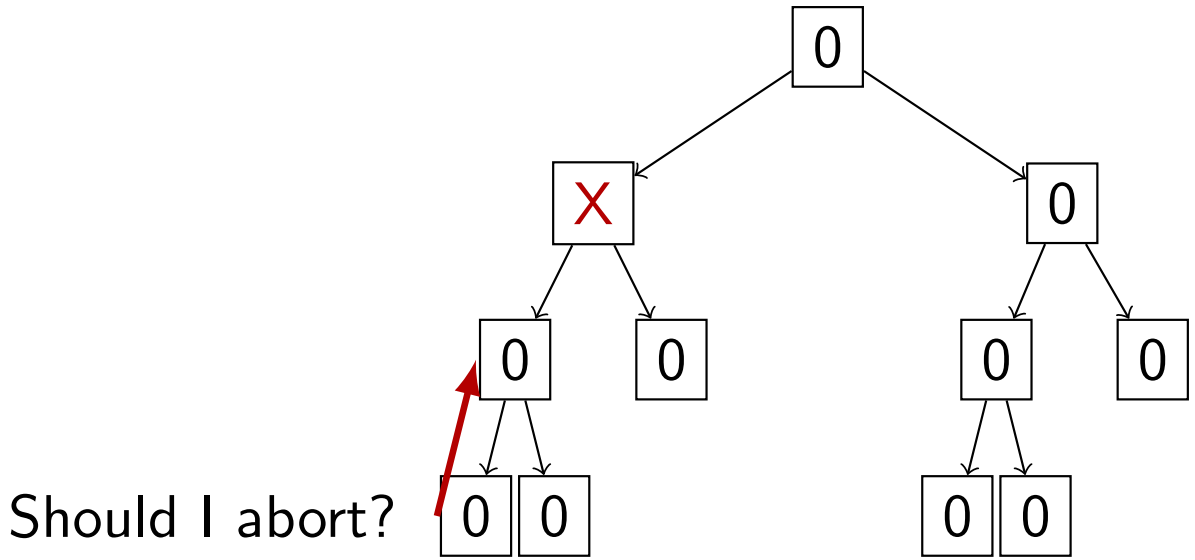

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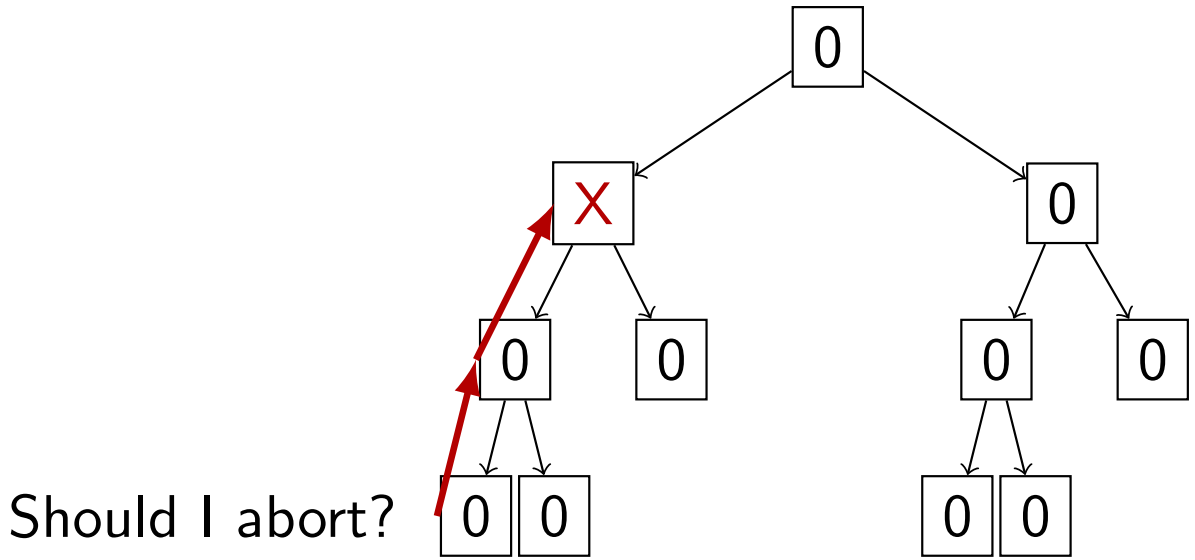

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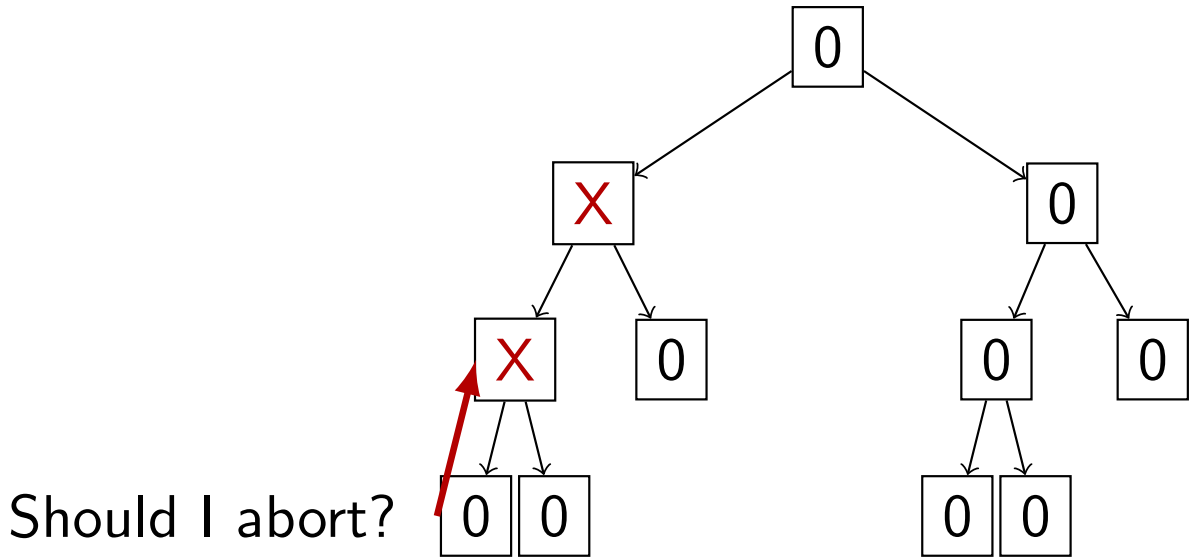

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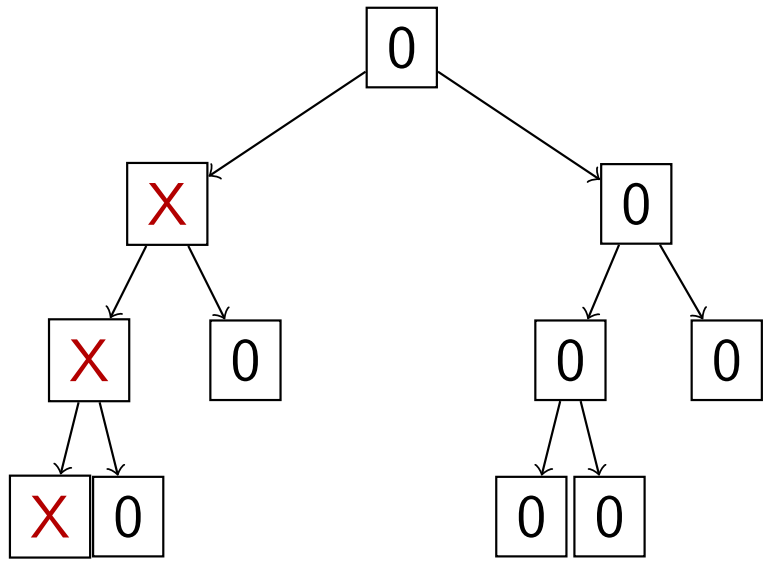

Should I abort?
Yes

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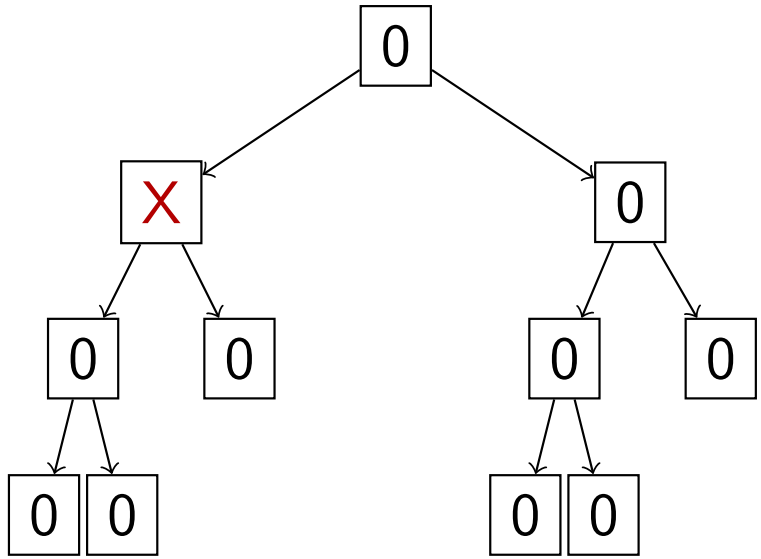

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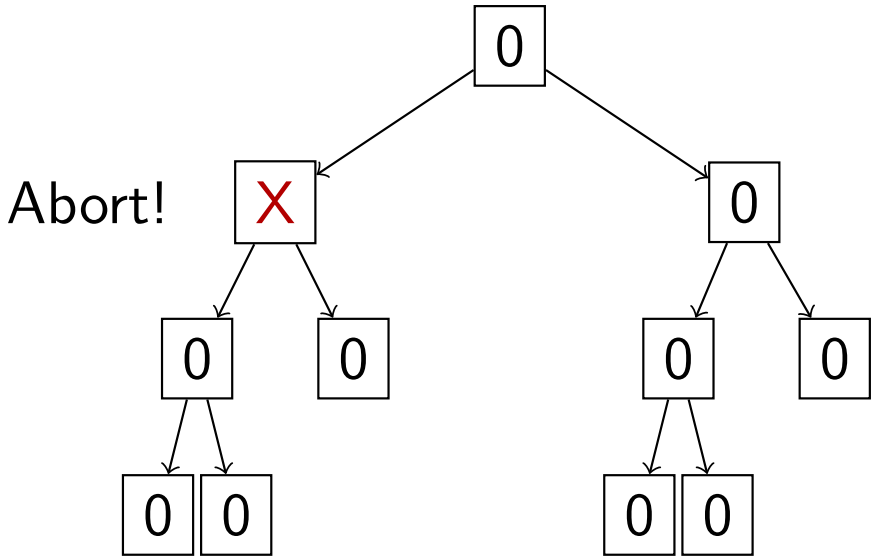

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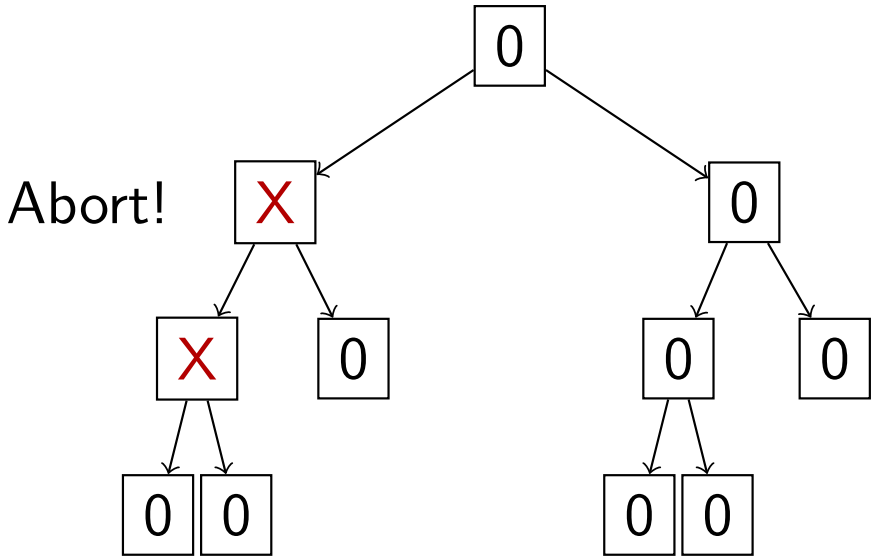

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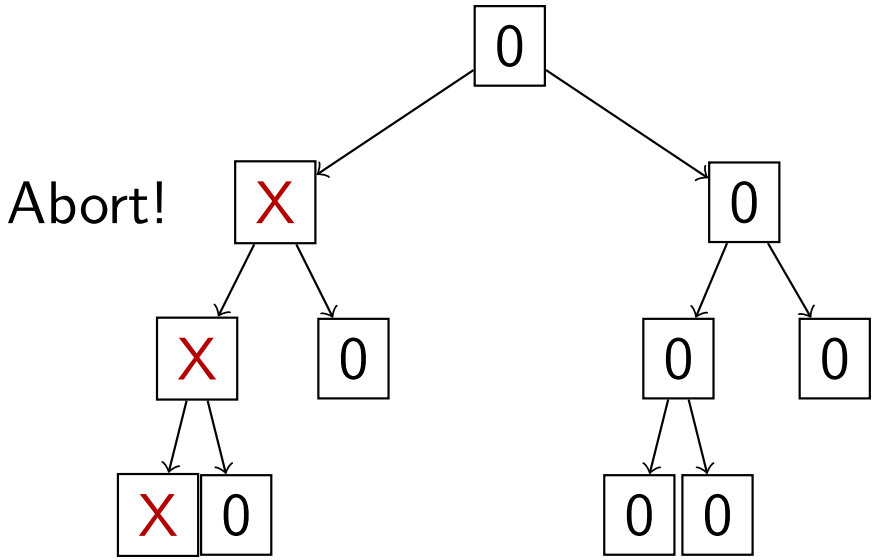

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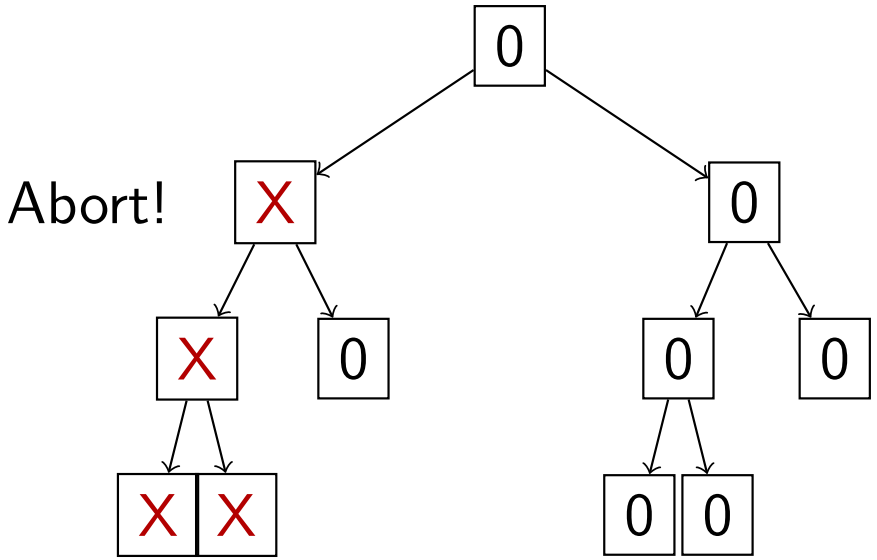

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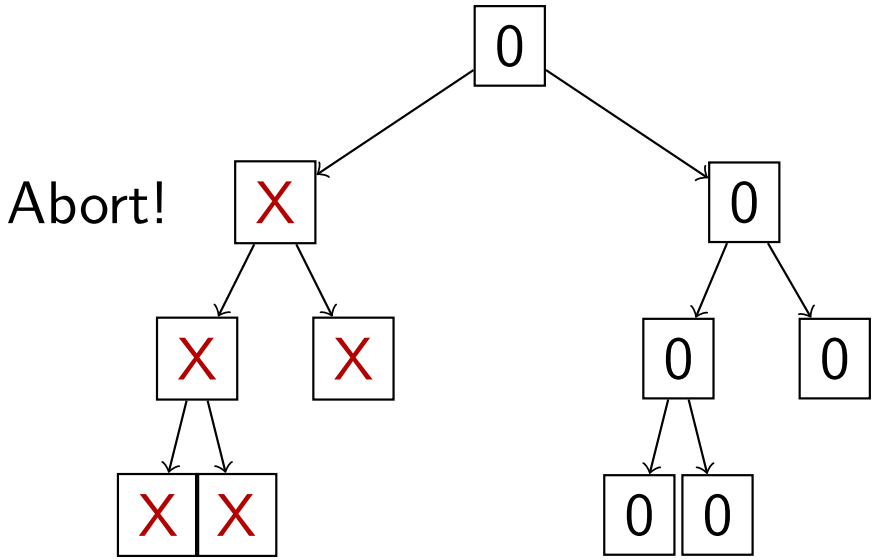

High-level Performace

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  - Polling is expensive (linear in depth of node)
  - `abort` is cheap (constant time, single memory access).
- **Abort-Down**
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High-level Performace

- **Poll-Up**
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  - *Really simple implementation.*
- **Abort-Down**
  - Polling is cheap (constant time, single memory access).
  - `abort` is expensive (linear in the *size* of the subtree).
  - *Code is much more complex.*
  - *Some extra overhead, currently using a locking implementation.*

Outline

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2. Evaluation
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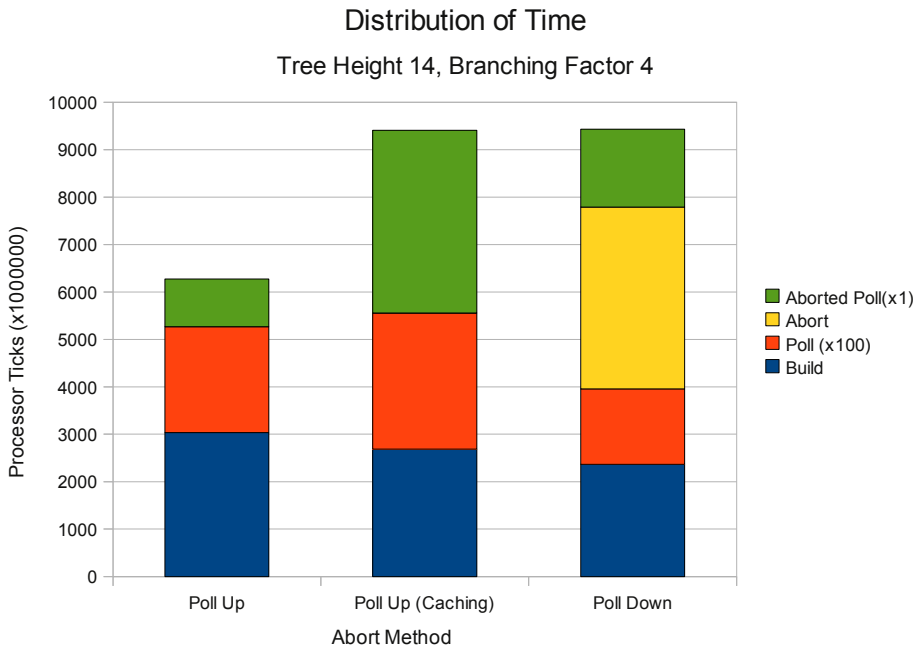
Different Flavors of Abort

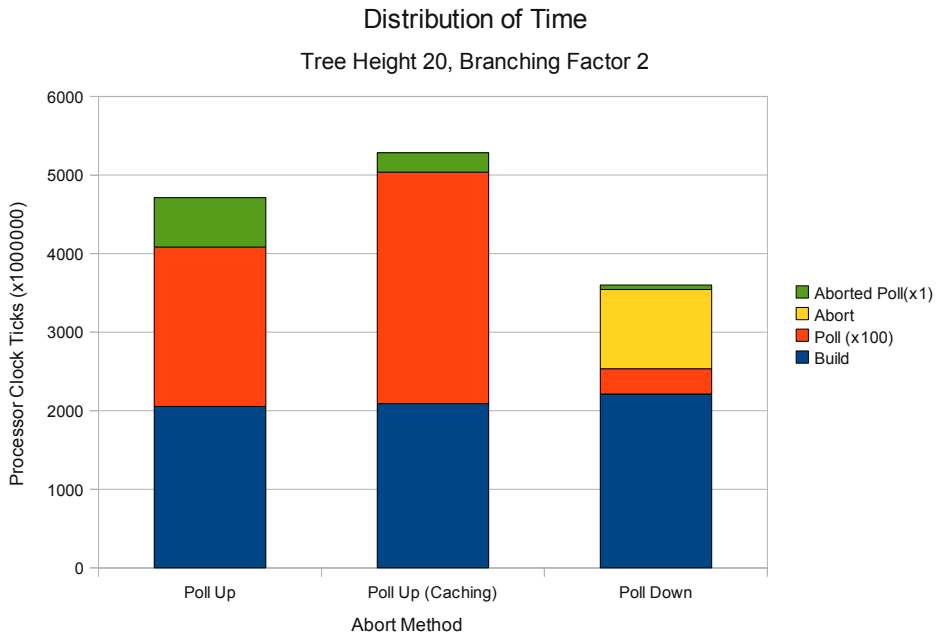
- Compare the different abort techniques.
  - **Build** a tree of height 14 and branching factor of 4.
  - **Poll** at each leaf 100 times.
  - **Abort** the root.
  - **Poll** at each leaf.



- Note that **abort** is serial.

Different Flavors of Abort

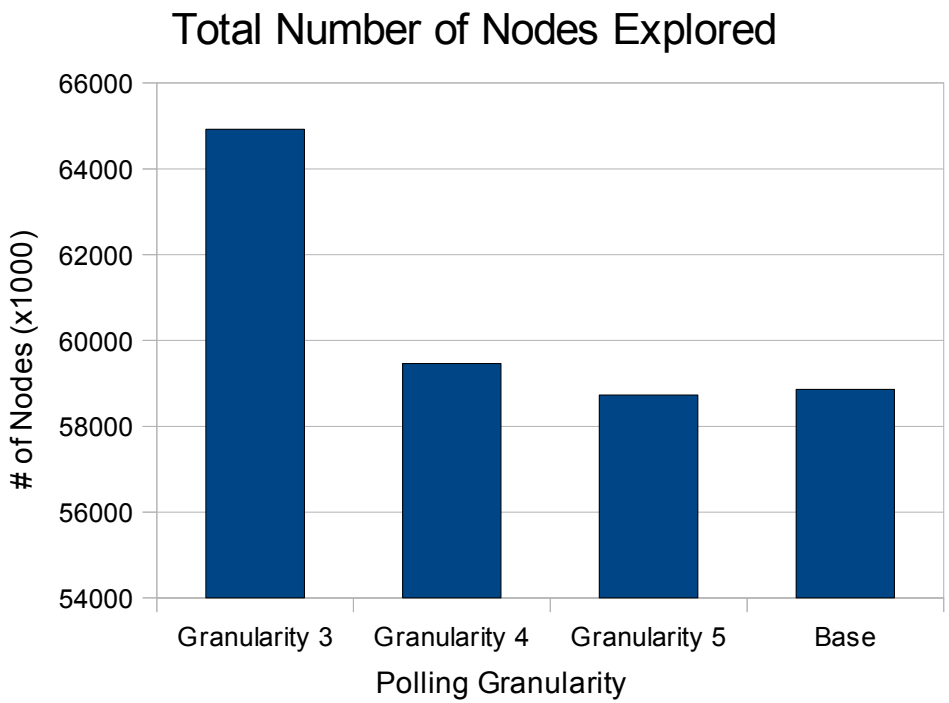
- Compare the different abort techniques.
  - **Build** a tree of height 20 and branching factor of 2.
  - **Poll** at each leaf 100 times.
  - **Abort** the root.
  - **Poll** at each leaf.



- Note that **abort** is serial.

Polling Granularity Effects – Nodes Explored

- We're running our ported pousse code (with some instrumentation).
- **Granularity N** doesn't poll at the lowest *N* levels of the tree.
- **Base** only checks abort in the loop that spawns the child computations.



Polling Granularity Effects – # of Polls

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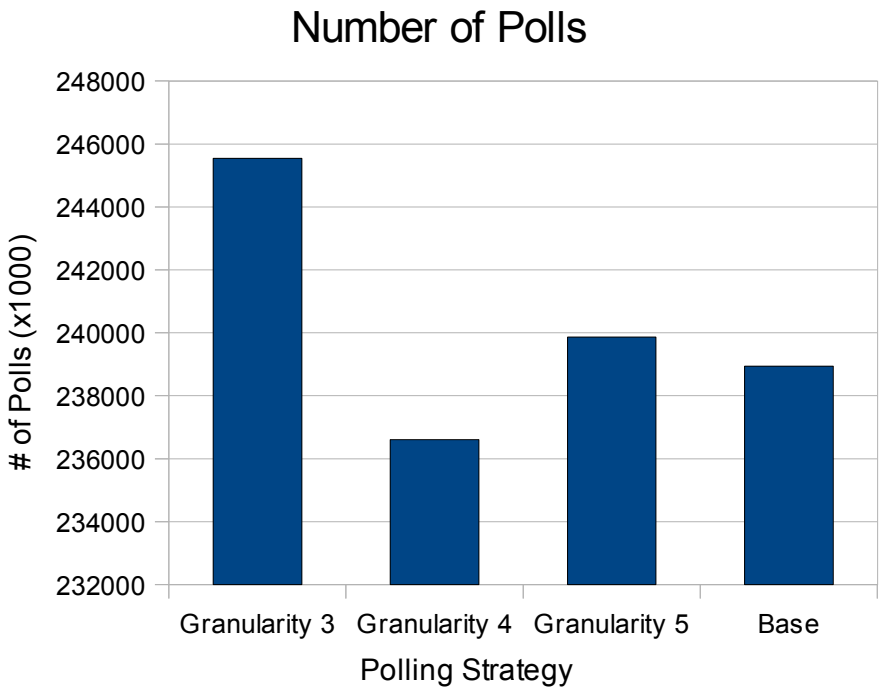

Polling Granularity Effects – # of Aborts

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- **Granularity N** doesn't poll at the lowest *N* levels of the tree.
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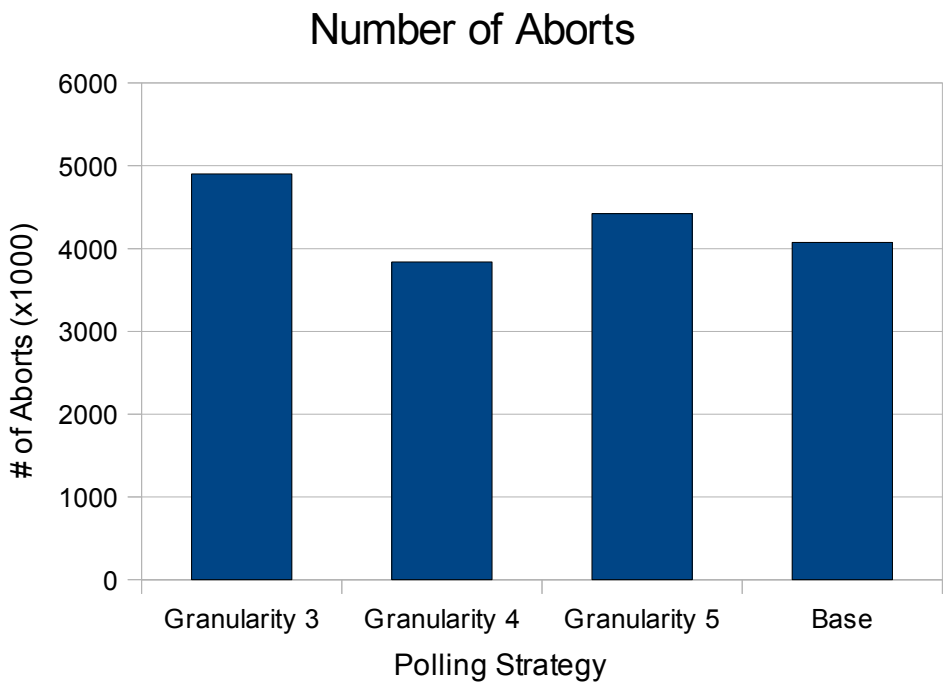

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Experience Porting Cilk Code

- We ported Cilk Pousse [1] from cilk to cilk++.

	Lines
Cilk Pousse	956
Cilk++ Pousse	1011
Increase	≈5.07%

- Pretty simple with the inlet translation.
  - Most annoying part is adding the calls to poll.
    - This can use some tuning.
  - Code is a little more difficult to read, but not too bad.
- The real problem is that this changes the interface.
  - Need to pass around the abort object.
  - If it is used with an inlet, need to add continuation.
  - Whole-code transformation is bad.

[1] `people.csail.mit.edu/pousse/`

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Speculations on Speculative Parallelism

- Speculative parallelism is definitely implementable as a library.
  - Native runtime support might be more efficient/nicer.
- Lack of some abstraction features makes using it at the high-level require interface changes.
- ...but, using it locally at the leaves does not leak into the rest of the code.