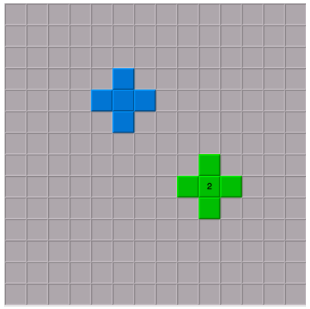
The Liquid Metal Blokus Experiment



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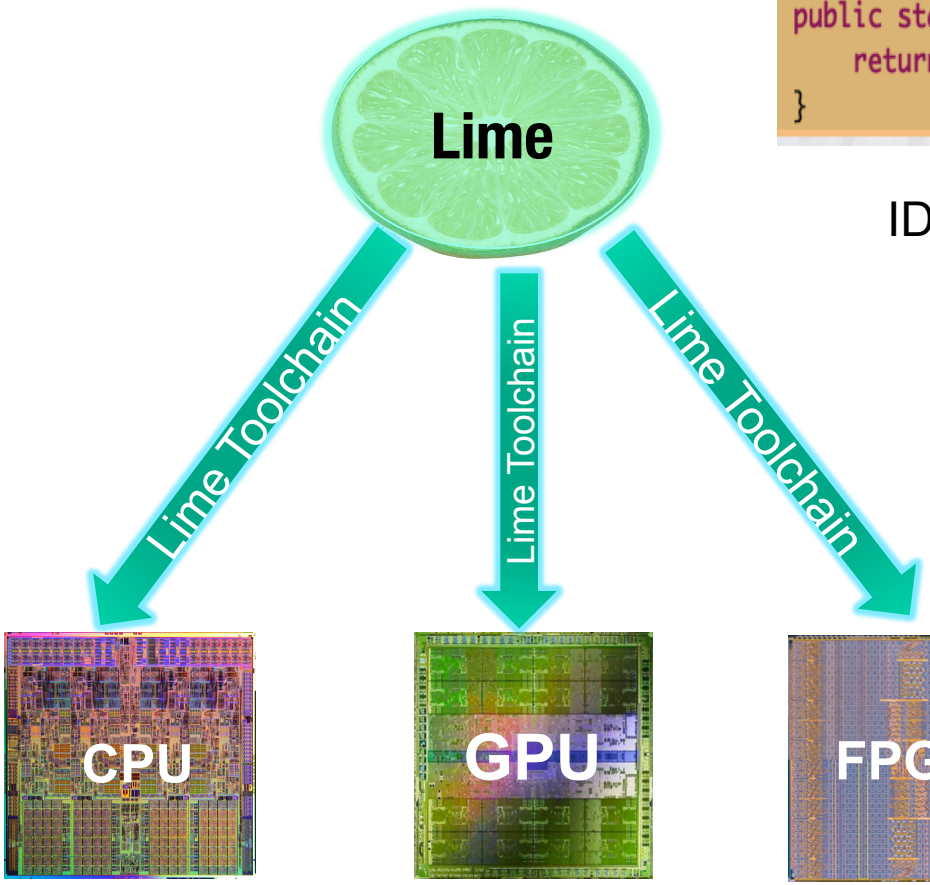
Goal: Make Heterogeneous Platforms Accessible for Mainstream Use

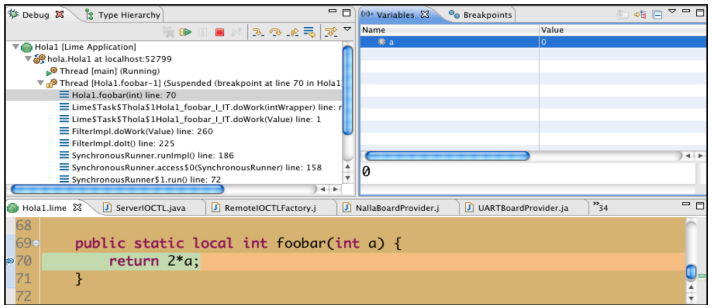
Vision:



High-Level Java-Derived Language

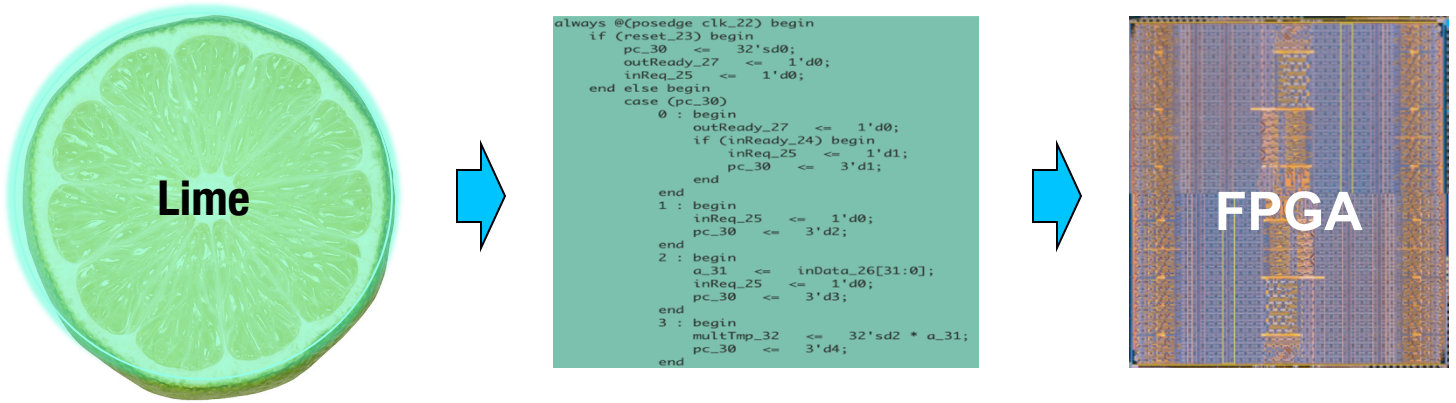
```
public static local int foobar(int a) {
    return 2*a;
}
```

IDE, Compiler, Debugger, Cloud Synthesis



Platform:
Hardware + Runtime

Is High-Level Synthesis (using Lime) viable?



Using a high-level language, can a developer design hardware whose quality matches hardware designed with standard tools?

An Experiment

Blokus Demo

Lime

The Liquid Metal Programming Language

What is Lime?

Lime = Java + Isolation + Abstract Parallelism

Isolation: ability to move computation

- **local** keyword
- Immutable types

Abstract Parallelism: freedom to schedule

- Stream programming model (**task, =>**)
- Data parallel constructs (**@** map, **!** reduce)

The Lime Development Experience

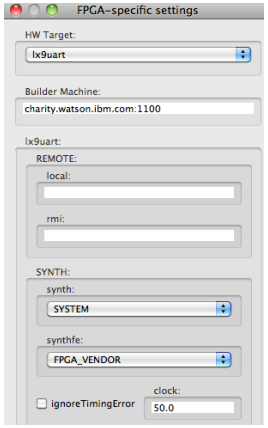
1. Prototype in standard Java

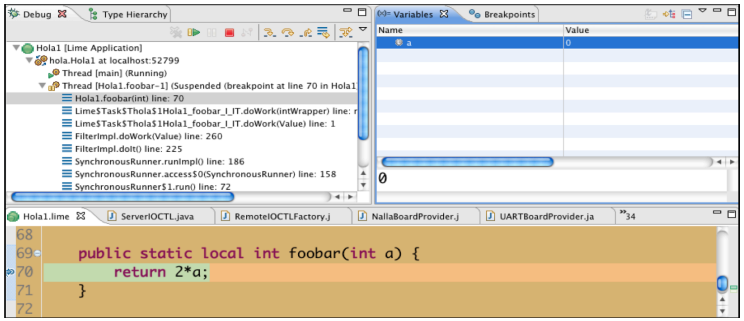
- Lime is a superset of Java
- **Java-like Eclipse IDE (editors, debugger, navigation)**

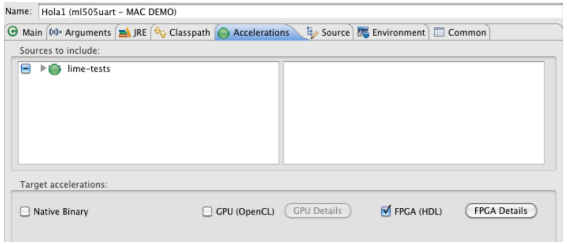
2.Gentle, incremental migration to parallel Lime code

Lime language constructs restrict program to safe parallel structures

- Isolation
- Immutability
- Safe Deterministic Parallelism
- Bounded Space







Implementing Blokus player in Lime

```
public interface Player {

    /**
     * Return some descriptive name for this Player
     */
    public string getName();

    /**
     * Reset the state of the game to g.
     */
    public void reset(Game g);

    /**
     * What is the next move, after the opponent makes move m?
     */
    public Move nextMove(Move m);

}
```

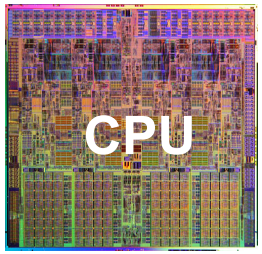
Player is stateful object

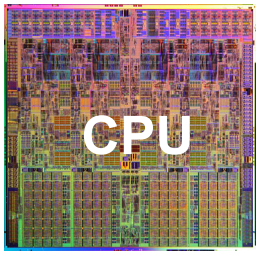
Relocation Brackets **[( )]** indicate tasks that can relocate to device

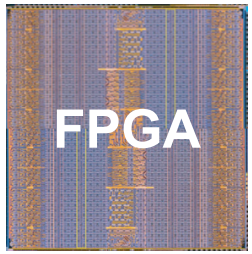
Connect operator **=>** abstracts communication

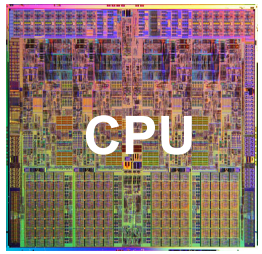
Task graph expression specifies coarse-grain dataflow:

```
source() => ([ task new BlokusPlayer().nextMove ]) =>  sink()
```









Lime for a standalone (headless/no host) deployment

```
([ task receiveMove => task move => task sendMove ])
```

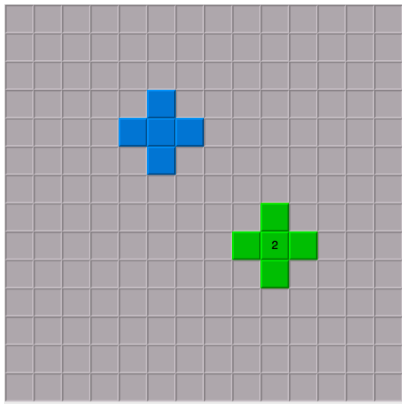
Entire task graph inside relocation brackets

Lime Native Interface

```
import lime.lang.annotations.lni.InputPins;
import lime.lang.annotations.lni.OutputPins;

public class NativeBlokus {

    @InputPins({"opp_move:72", "opp_rdy"})
    @OutputPins({"opp_ack"})
    public static native local byte[[9]] receiveMove();

    @InputPins({"lime_ack"})
    @OutputPins({"lime_move:32", "lime_rdy"})
    public static native local void sendMove(byte[[4]] b);

}
```

Implement “native” methods in VHDL/Verilog/etc.

Blokus AI Algorithm



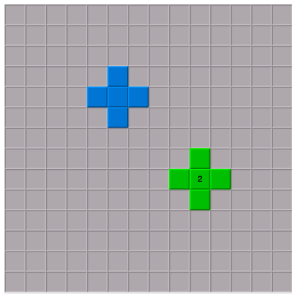
Minimax tree search
- Based on board **evaluation function**

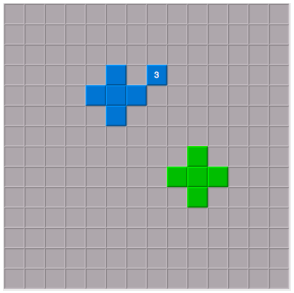
Fixed budget (1 sec response)
- Iteratively deepen tree until budget exhausted

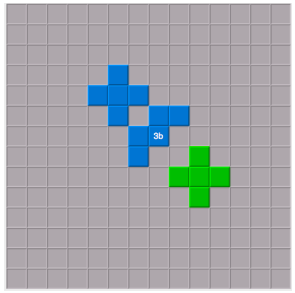
Maximum bounded tree size
- Statically allocated data structures – no dynamic memory allocation

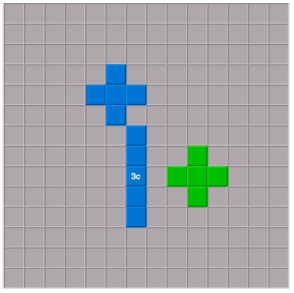
Relatively simple algorithm for software AI players
- Relatively complicated data structures for hardware implementation

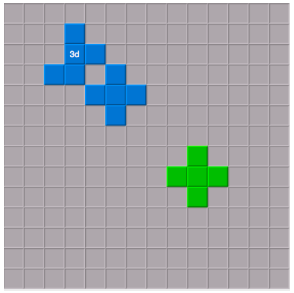
Minimax Step 1: Enumerate all possible moves

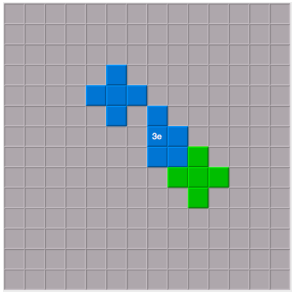












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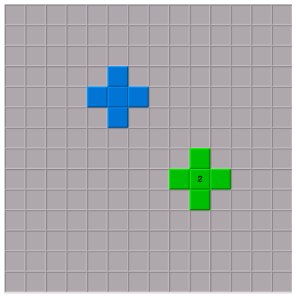
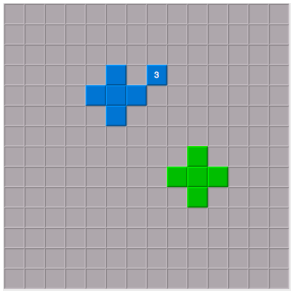
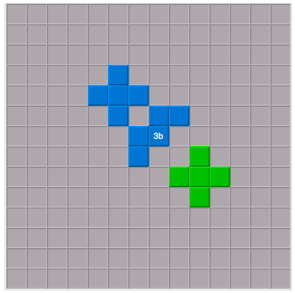
Minimax Step 2: Score each move with *evaluation function*





100



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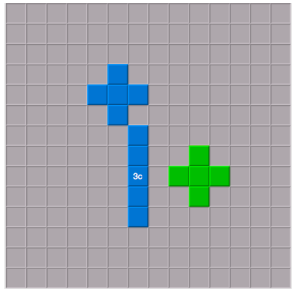

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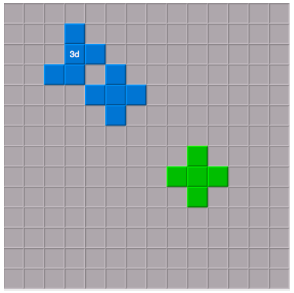

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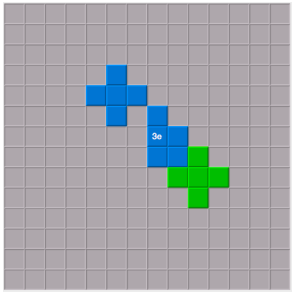
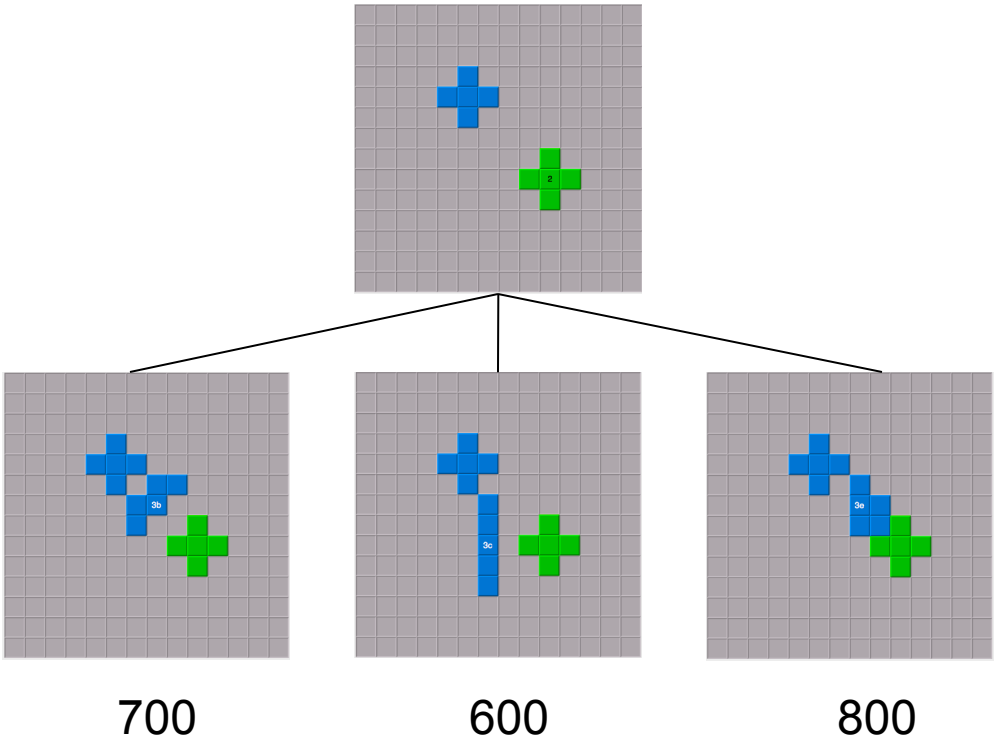


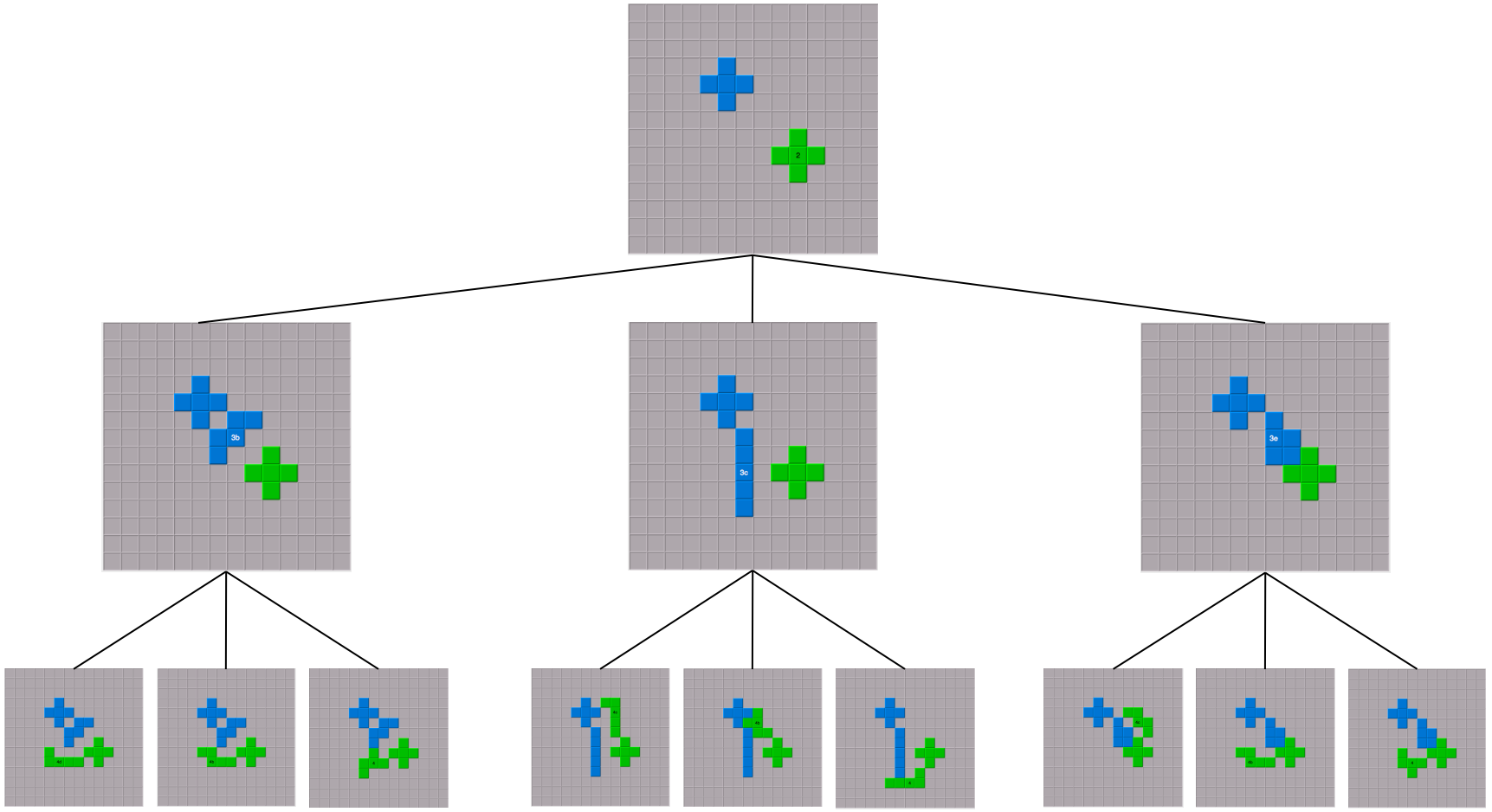
800

....

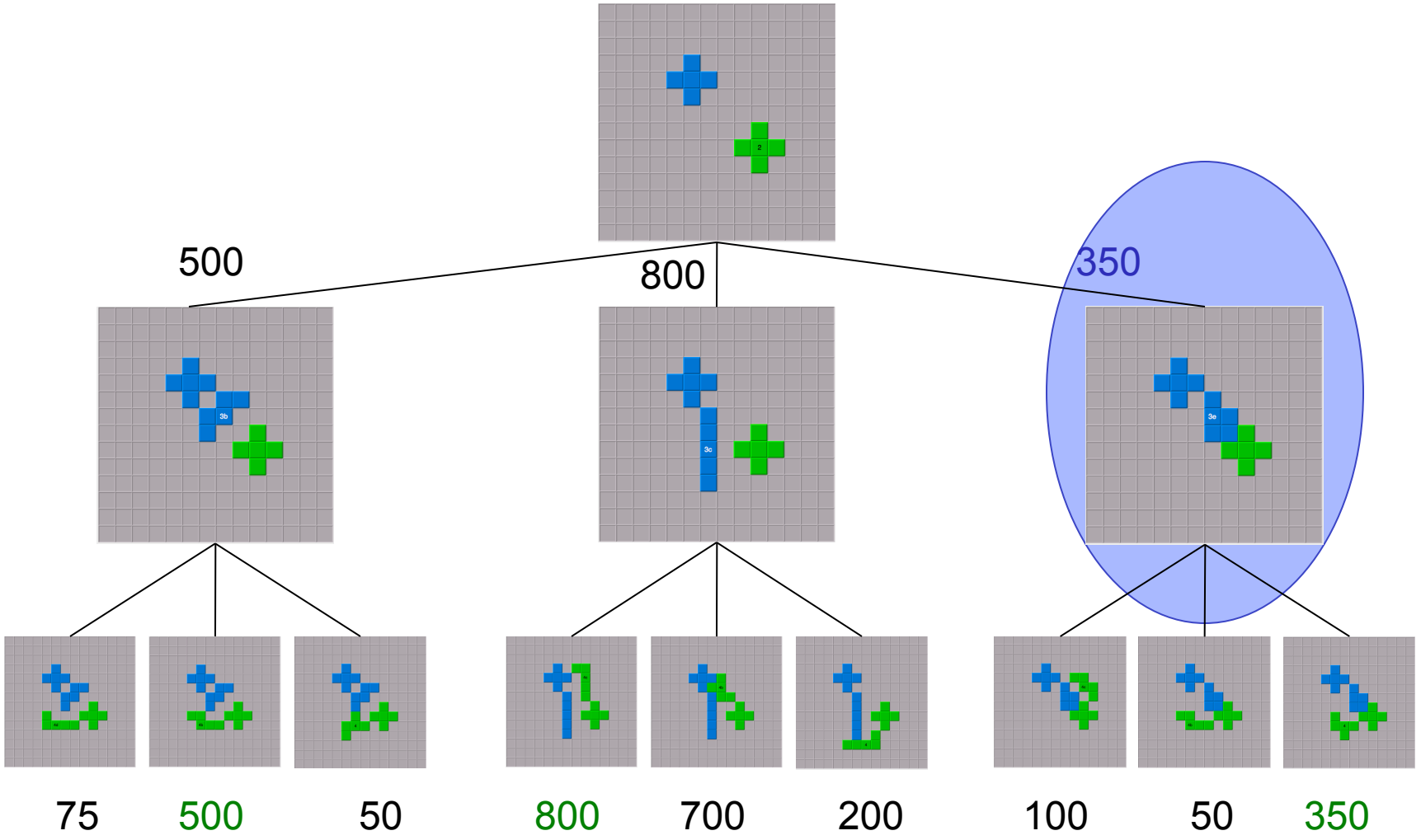
Minimax Step 3: Pick best *k* moves and add to search tree



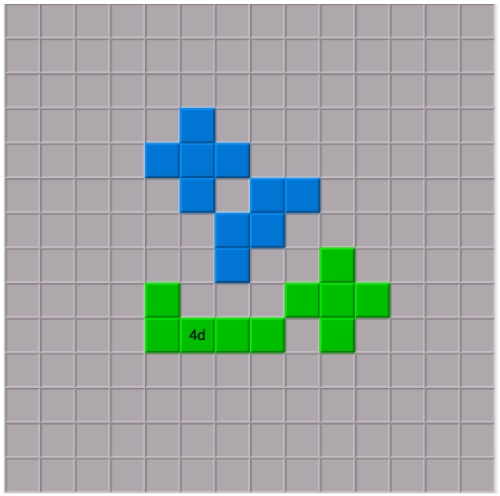
Minimax Step 3: Iterate until budget exhausted

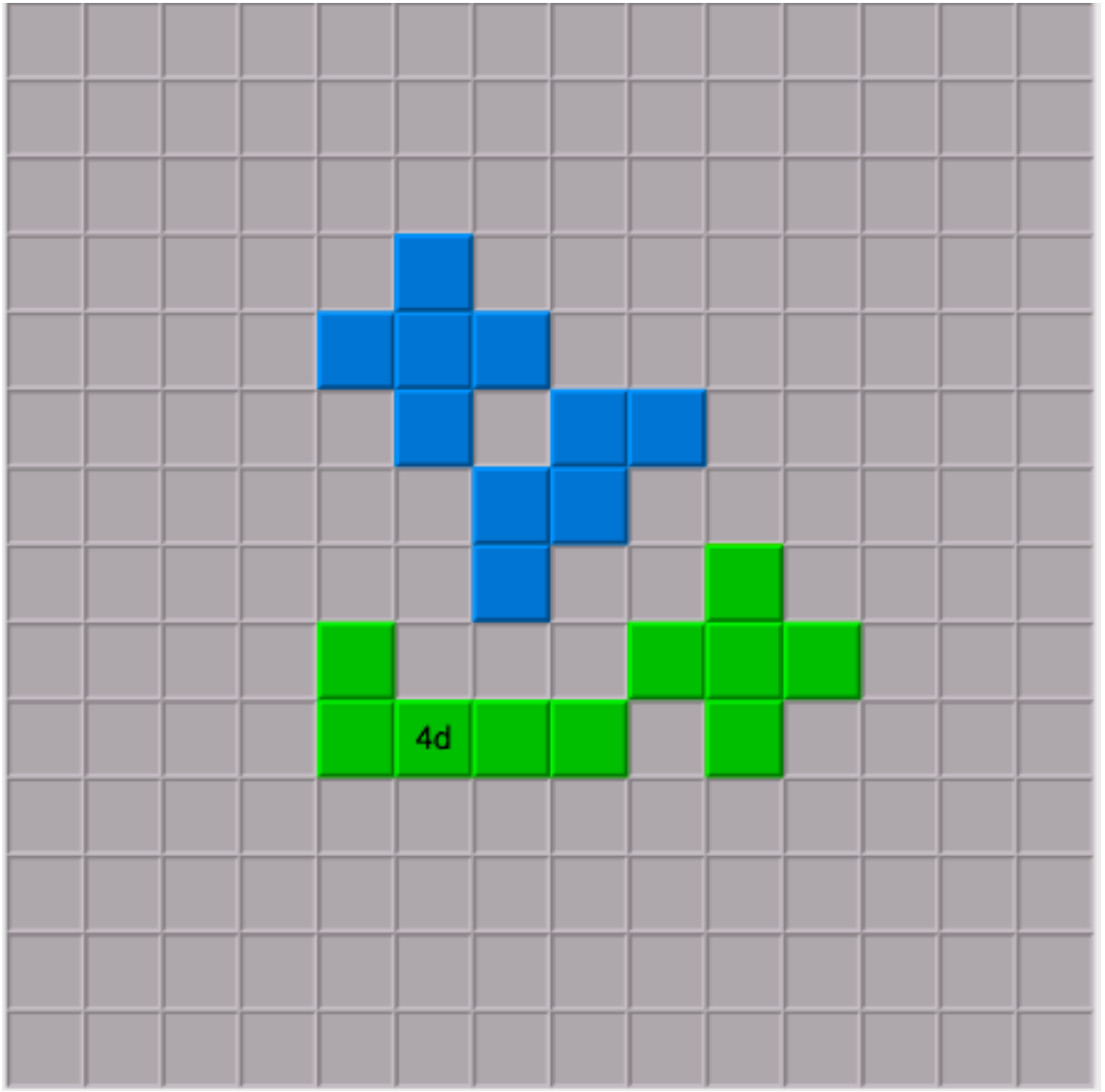


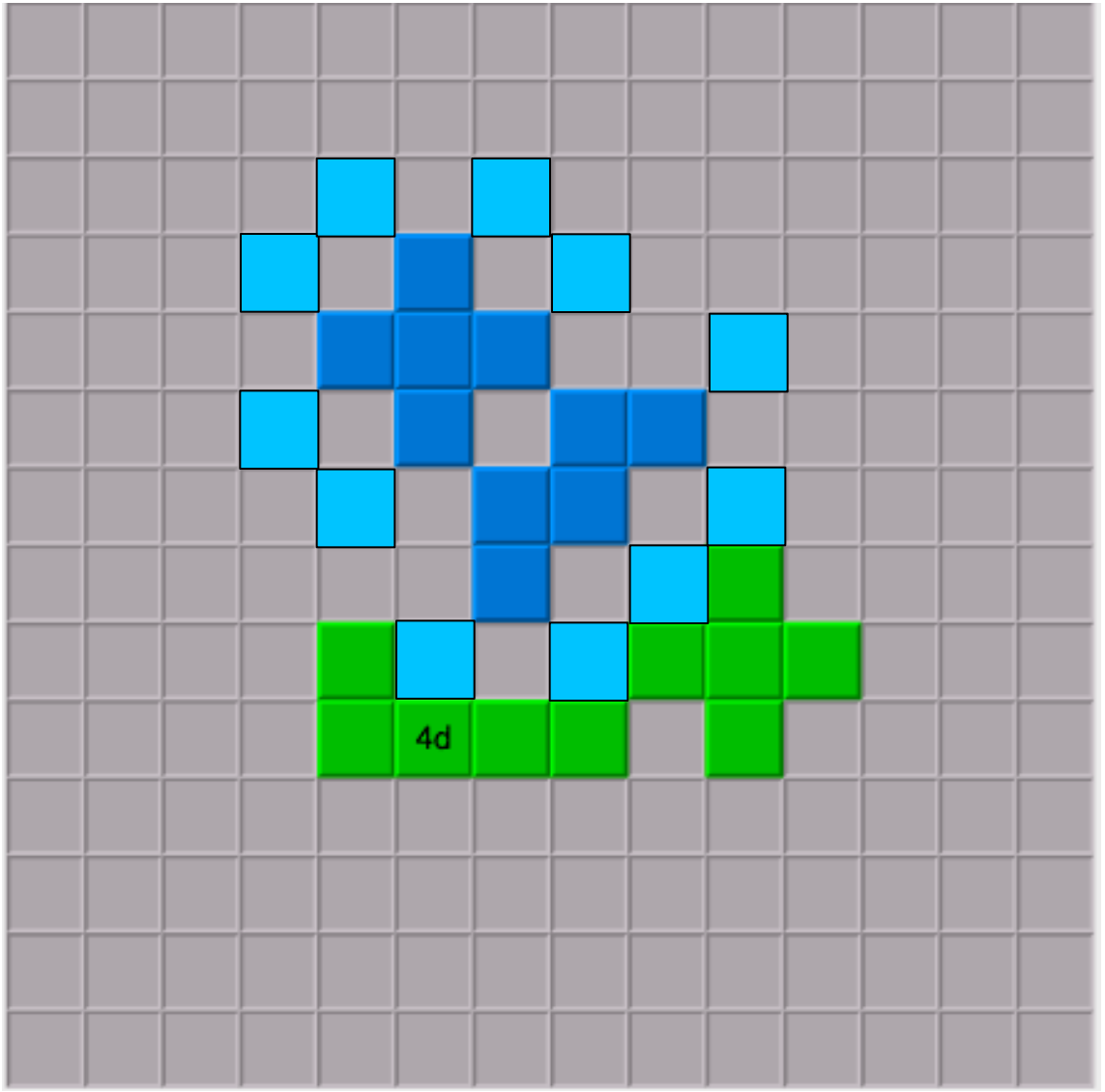
Minimax Final Step: Choose best move via minimax reduction

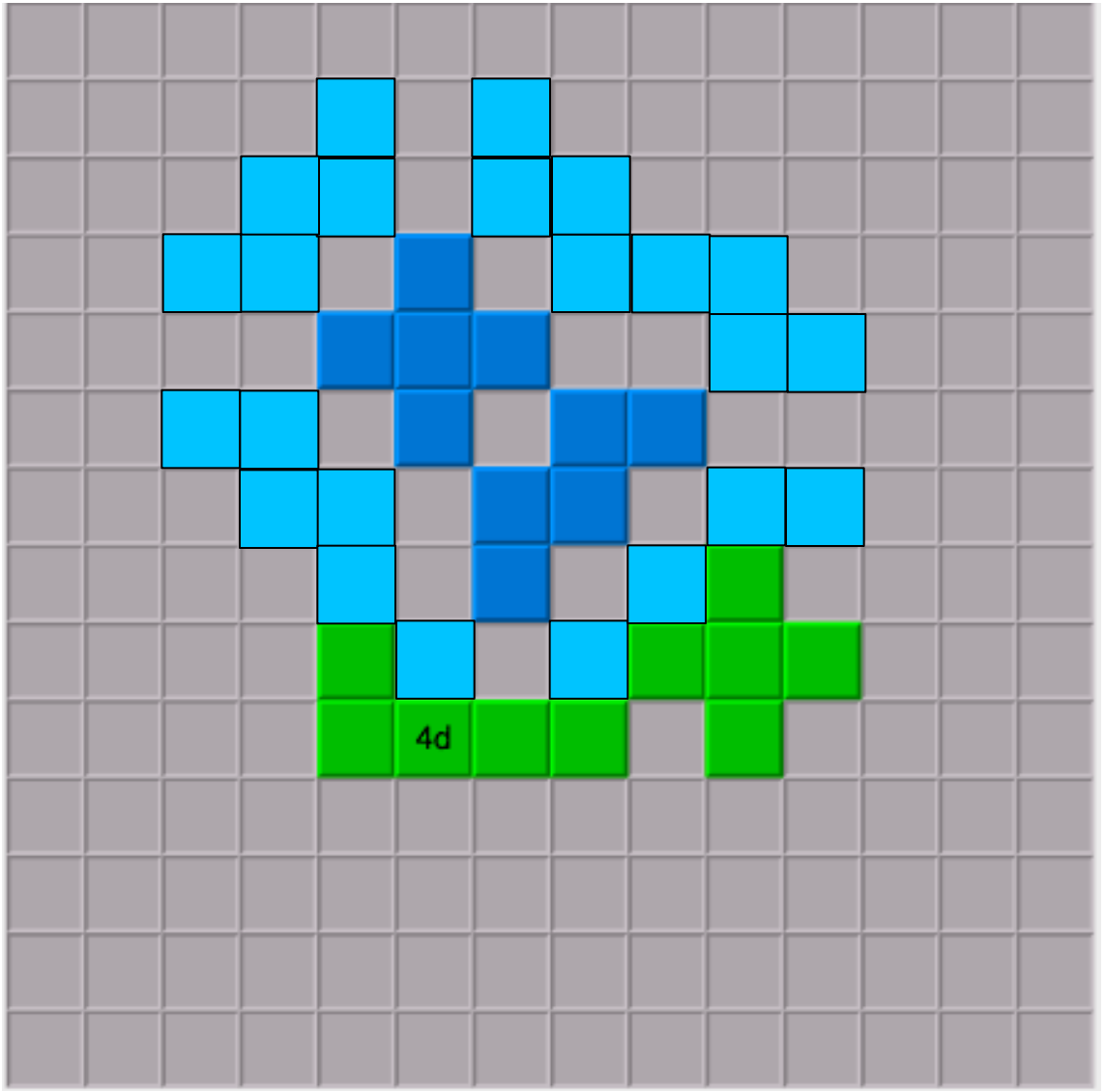


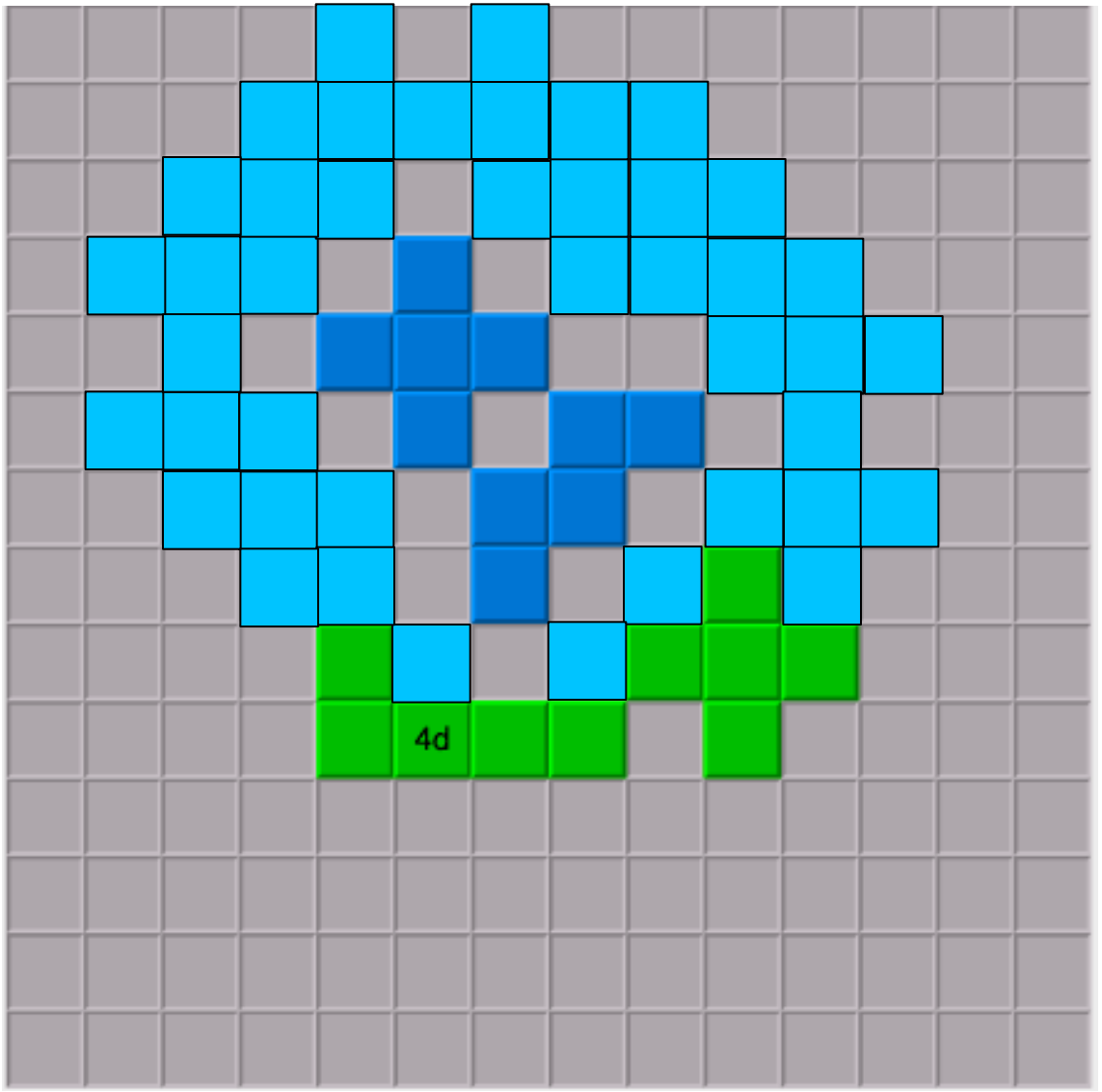
Territory-Based Evaluation Function

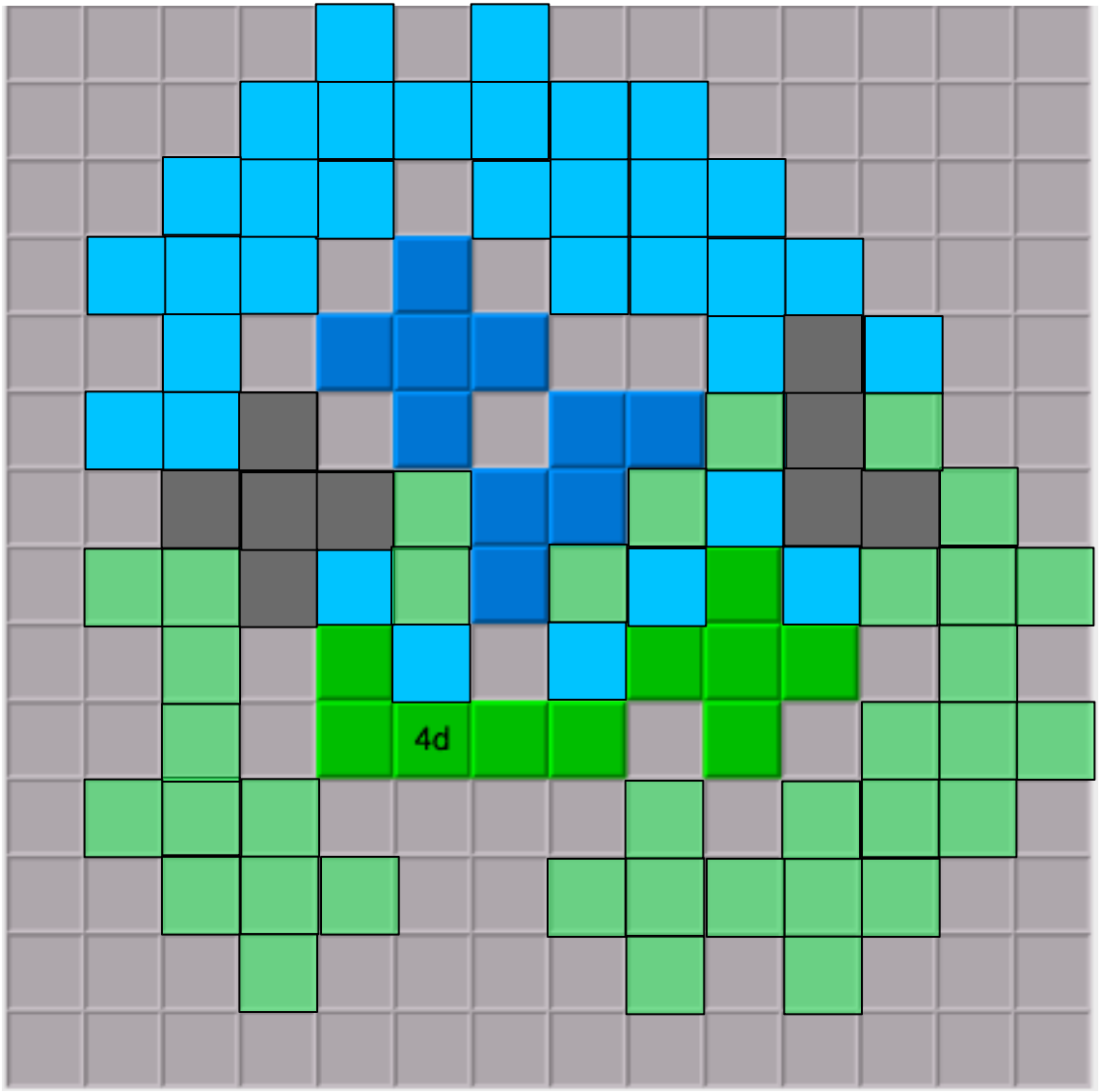
$f($  $)$











Inner loop of evaluation function in Lime

local qualifier guarantees isolation

value classes (programmable primitives)

bounded, immutable arrays

bounded integers

```
public static local Row[[14]] manhattanNeighbors(Row[[14]] g) {

    Row[14] r = new Row[14];
    Row upper = 0;
    Row mid = g[0];
    for (int<14> i){
        Row lower = (i == 13) ? (Row)0n : (Row)g[i+1];

        // manhattan propagation.
        r[i] = (Row)(upper | lower | (mid << 1) | (mid >>> 1));

        // update rows.
        upper = mid;
        mid = lower;
    }

    return new Row[[14]](r);
}
```

Lime type system invariants allow efficient translation inner loop – potentially one cycle

Implementation

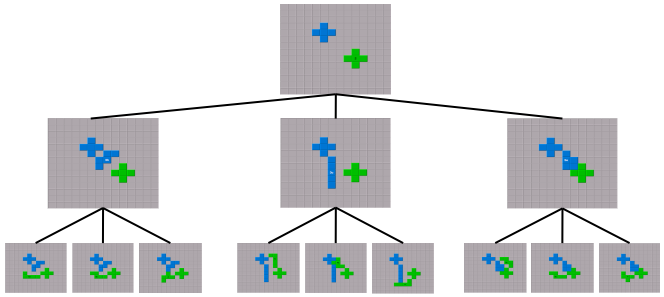
ML505 / Xilinx-Virtex 5 LX50T
7200 slices
48 DSP48E
2160 kB BRAM

Design Stats	
Lime Lines of Code	4231
Lines of Verilog generated	24,657
Lines of hand-written Verilog	186
Frequency	85 MHz
LUTs	15,917 (55.3%)
Flip Flops	11,050 (38.4%)
18kB BRAMs	64 (54.2%)
DSPs	14 (29.2%)

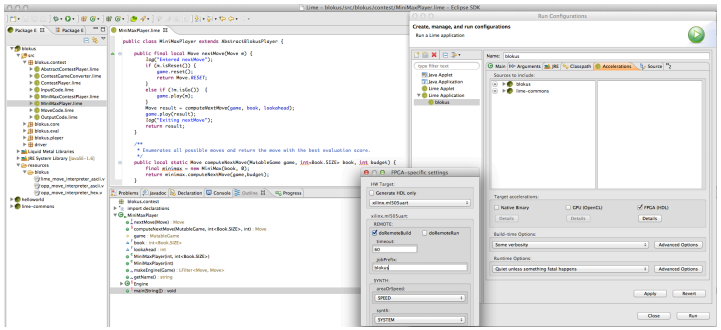
Lessons Learned So Far

AI Search: Ideal domain for high-level synthesis

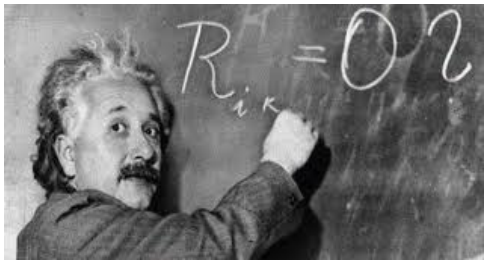
- Algorithmic tuning
- Iterative development cycle
- High computation/communication ratio



Lime development cycle rocks



Software engineer can implement complex hardware in Lime



Using a high-level language, can a developer design hardware whose quality matches hardware designed with standard tools?

Can the Lime team design a Blokus player in Lime that can win the 2013 ICFPT Design Competition?

Tune in early December!