Search Combinators

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Search heuristics are crucial.

Support for Search?

General Purpose Programming Language

"everthing is possible, nothing is easy"

Solver-Provided Options

"everything is easy, nothing is possible"

State-of-the-Art Modularity: Prolog

- ✓ label1(Vars1) , label2(Vars2)
- ✓ label1(Vars1) ; label2(Vars2)
- ✓ once(label1(Vars1))
- ✓ once((label1(Vars1),label2(Vars2)))

Lack of Modularity

- ✘ lds(label1(Vars1))

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- ✘ lds(label1(Vars1))
- ✘ lds((label1(Vars1) , label2(Vars2)))

Lack of Modularity

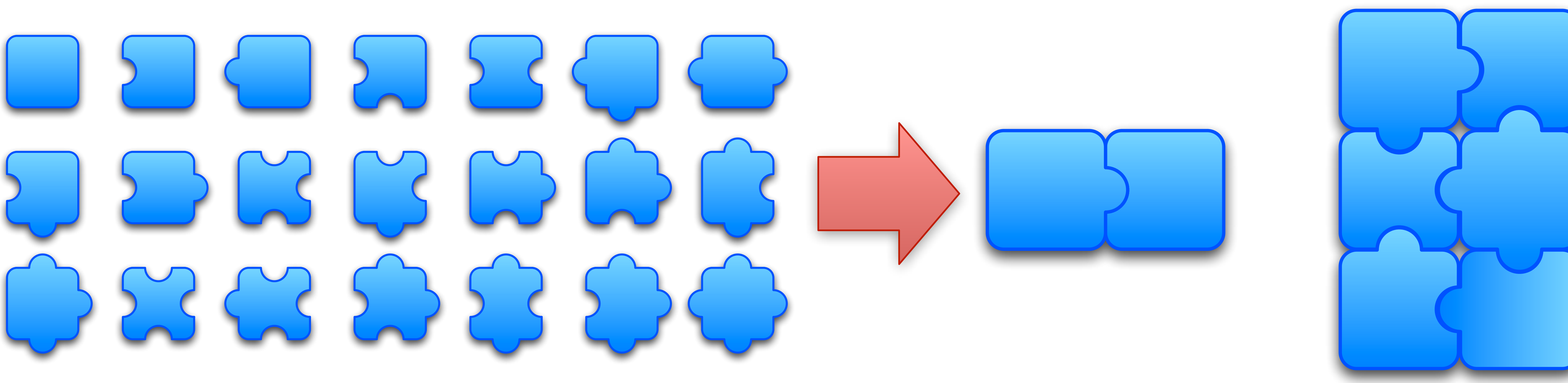
- ✘ lds(label1(Vars1))
- ✘ lds((label1(Vars1) , label2(Vars2)))
- ✓ lds_label1(Vars1)
- ✓ lds_label1_label2(Vars1,Vars2)

Can we do better?

- ✓ Lots of expressivity and flexibility
- ✓ Lots of productivity through high-level specifications
- ✓ Modular reuse of search specifications

Yes: Search Combinators

High-level modular building blocks



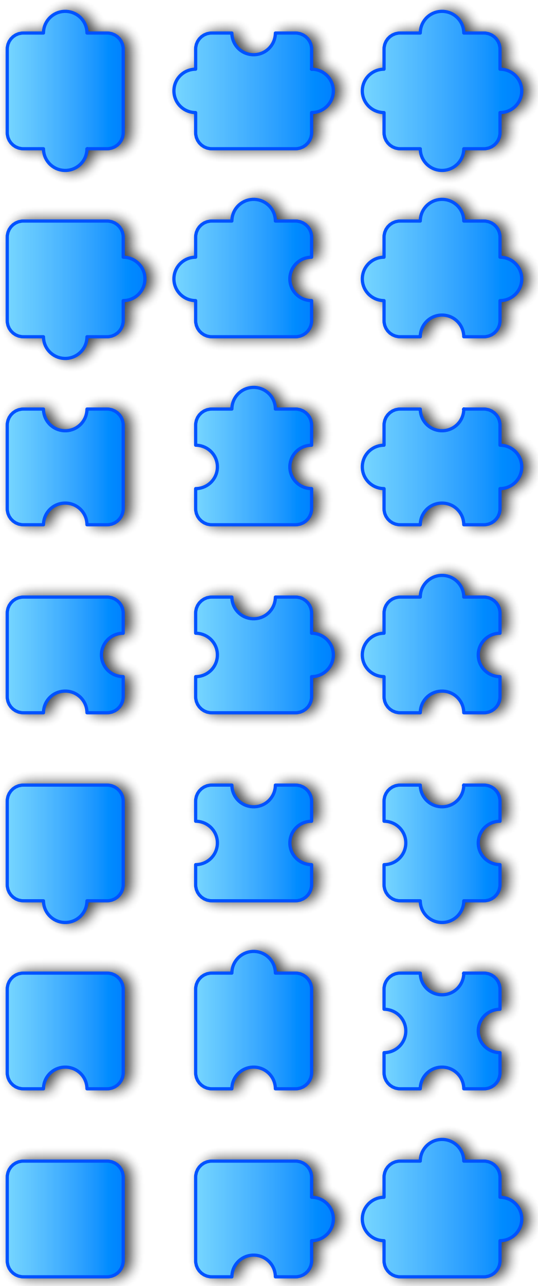
"Everything is possible and easy"

Base Search

```
s ≡
int_search(vars,var_sel,val_sel)
```

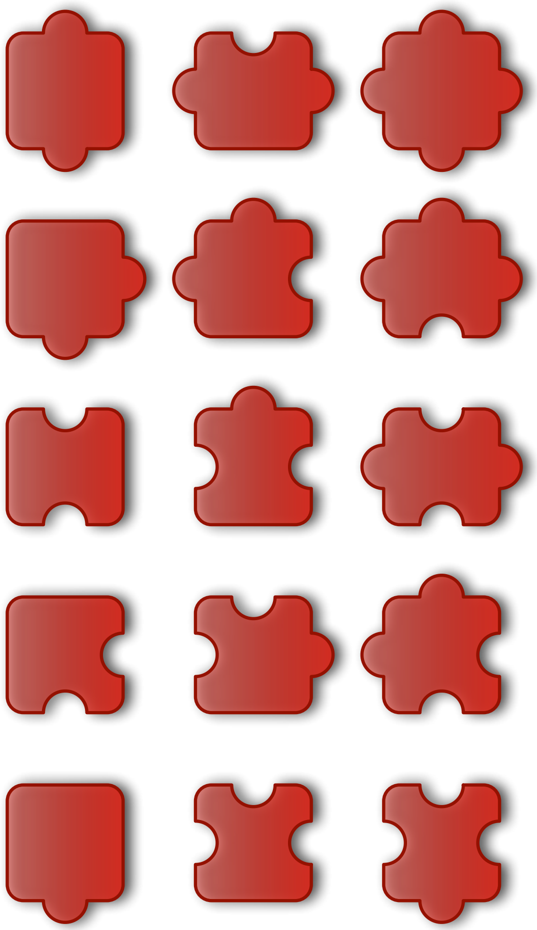
- provided by the solver
- augment with combinators

Combinators



prune
let(v,e,s)
assign(v,e)
post(c,s)
if(c,s_1,s_2)
and([s_1, s_2,..., s_n])
or([s_1, s_2,..., s_n])
portfolio([s_1, s_2,..., s_n])
restart(c,s)

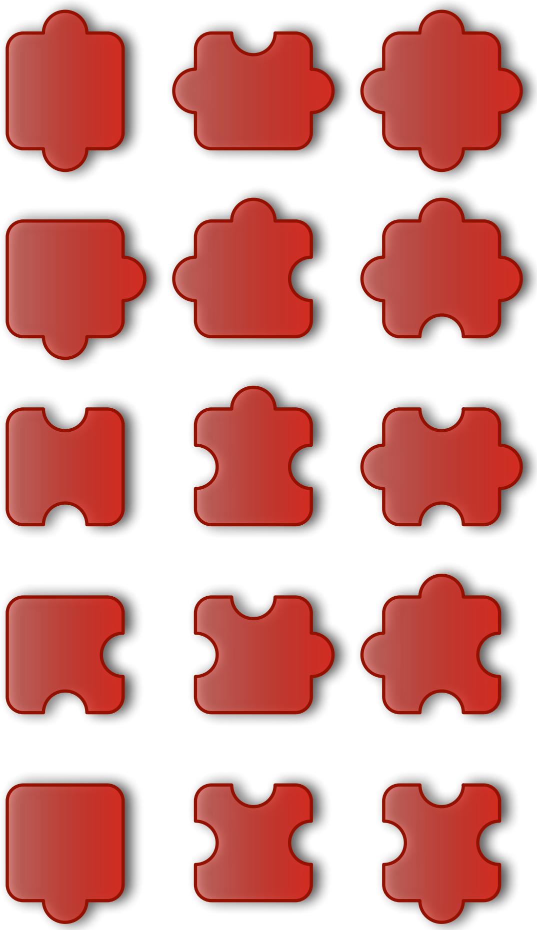
Statistics Combinators



depth(v,s)
discrepancy(v,s)

nodes(v,s)
failures(v,s)
time(v,s)

Statistics Combinators



depth(v,s)

discrepancy(v,s)

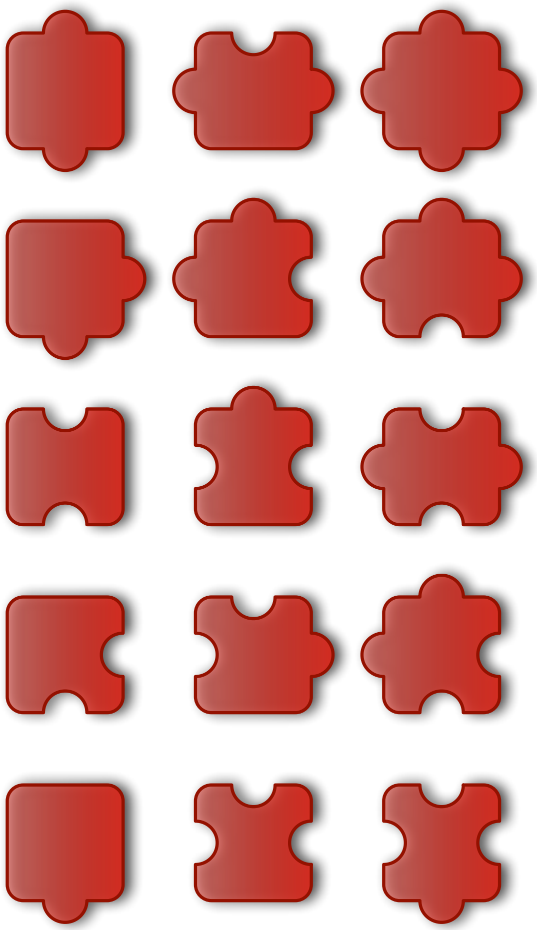
nodes(v,s)

failures(v,s)

time(v,s)

$$\texttt{if}(v < 5, \texttt{depth}(v, s_1), s_2)$$

Statistics Combinators



depth(v,s)
discrepancy(v,s)

nodes(v,s)
failures(v,s)
time(v,s)

if(depth < 5,s_1,s_2)

Reusable Abstractions

```
limit(c,s) ≡ if(c,s,prune)

for(v,l,u,s) ≡ ...

lds(s) ≡
  for(n,0,∞,
    limit(discrepancy ≤ n,s)
  )
```

Reuse Examples

```
✓ lds(int_search(vars,...))

✓ lds(and([int_search(vars1,...)
          ,int_search(vars2,...)])

✓ lds(or([int_search(vars1,...)
         ,int_search(vars2,...)])
  ...
```

More Abstractions

`bab`(*obj*,*s*)

`restart_bab`(*obj*,*s*)

`dicho`(*obj*,*s*,*lb*,*ub*)

`id`(*s*)

`hot_start`(*c*,s_1,s_2)

see paper

Radiotherapy Planning

```
bab(k,
  and([int_search(N,...)]
       ++
      [once(int_search(rowᵢ,...))
      | i in 1..n
      ]
     )
   )
```

Modular Syntax

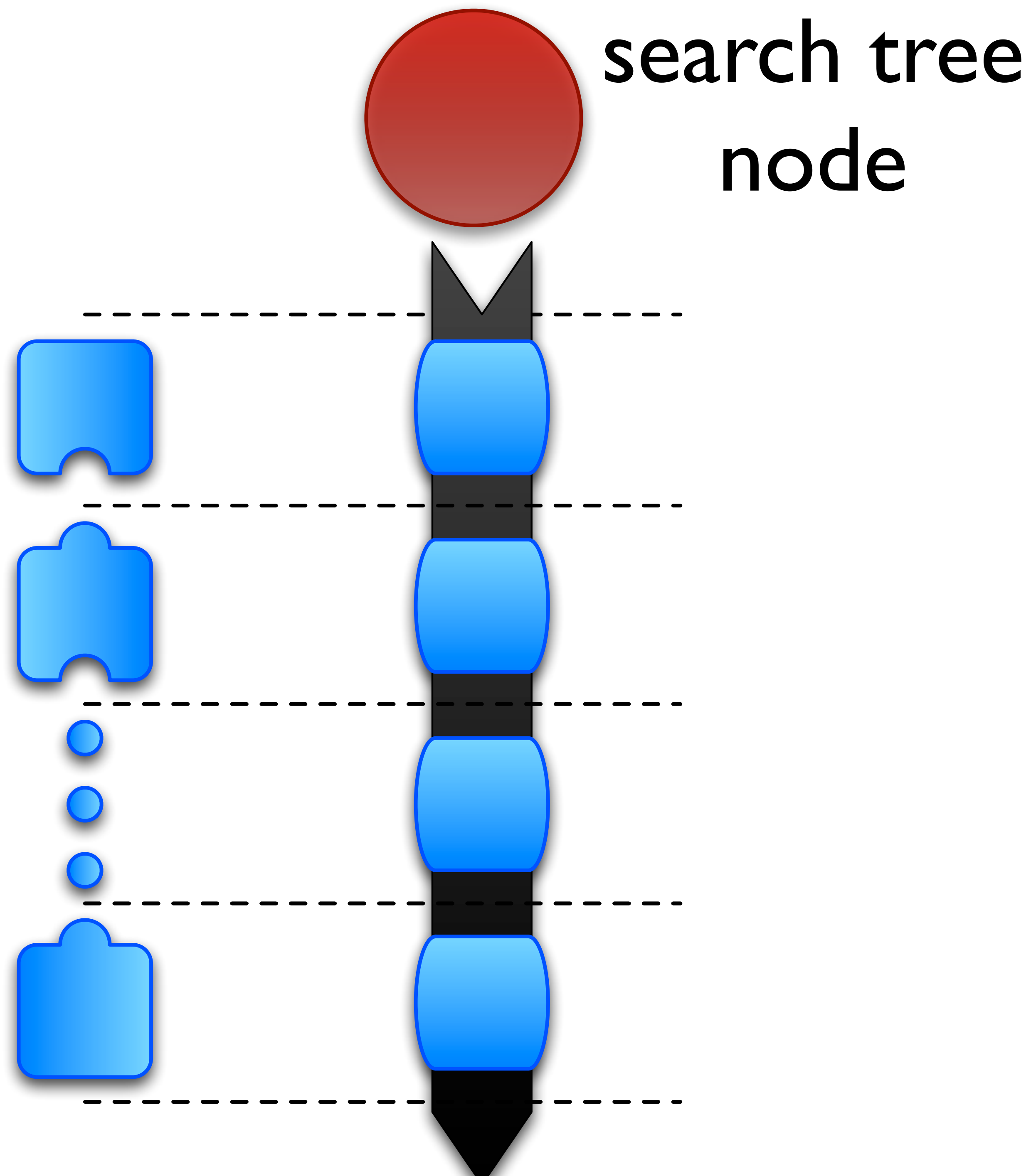
vs.

Modular Semantics

Modular Semantics

traditional modularity:

- each combinator is an atomic unit
- minimal interaction



Modular Semantics

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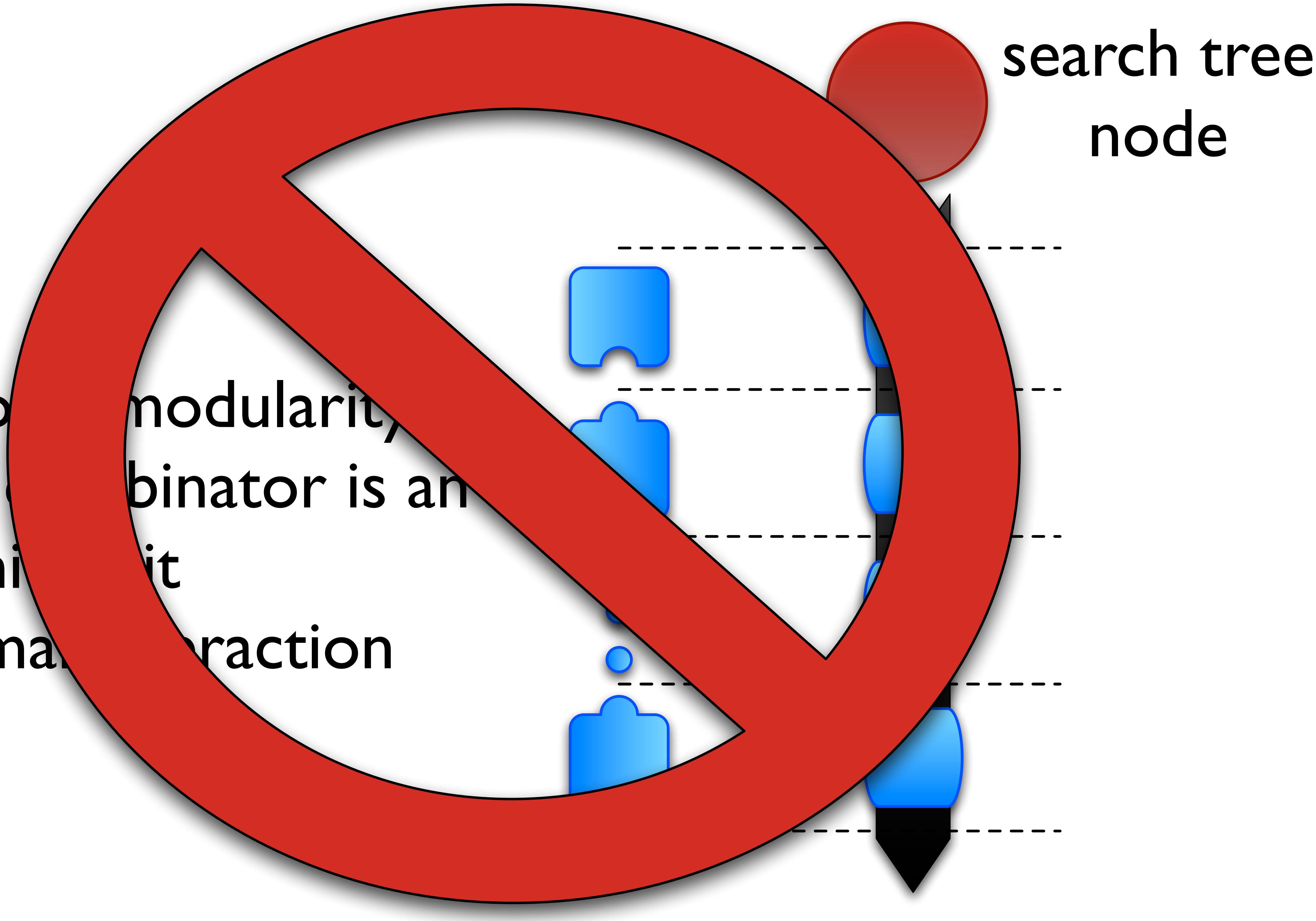


Modular Semantics

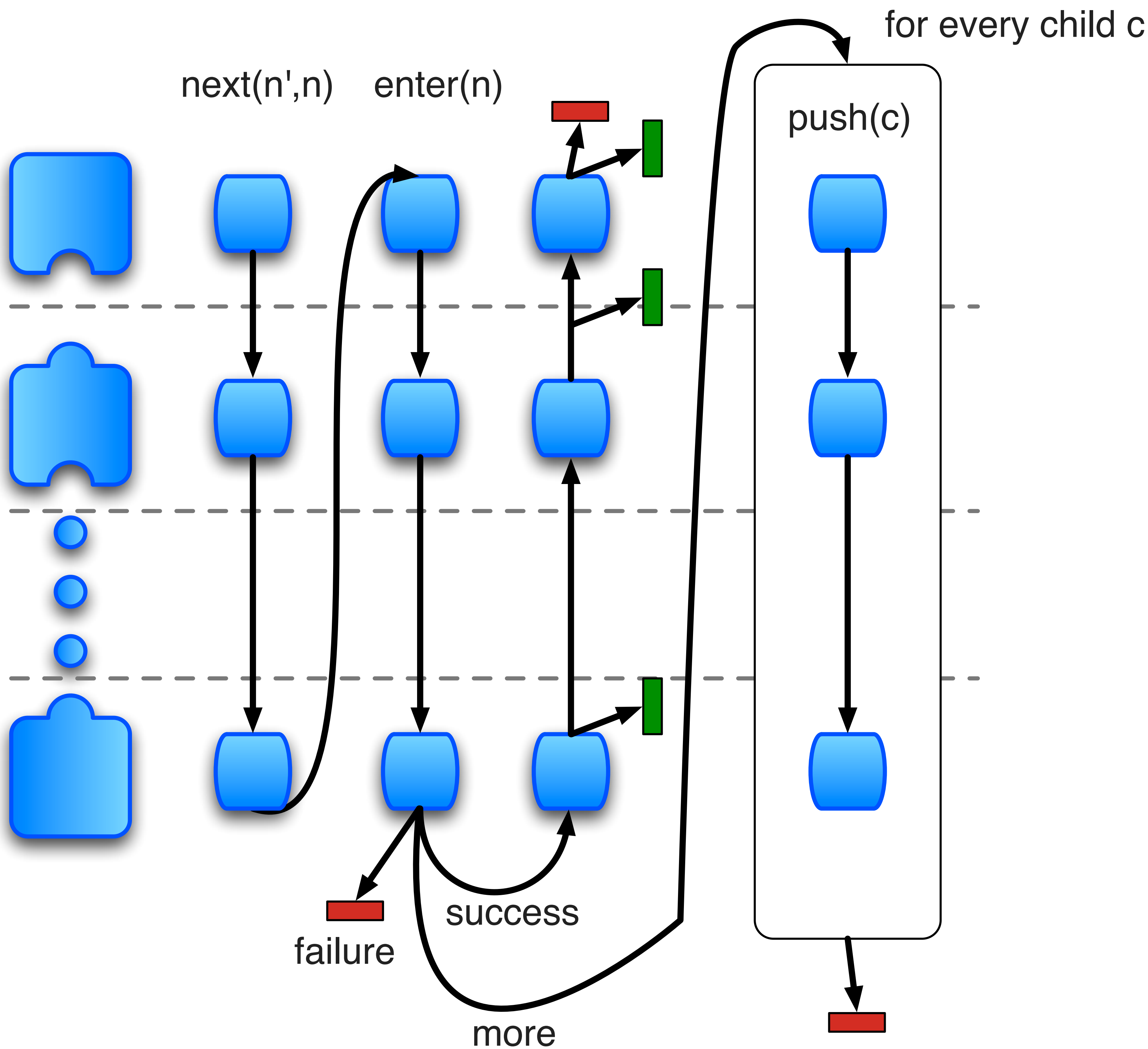
- cross-cutting behavior
- highly entangled in monolithic code

➡ "Aspect-Oriented Programming"

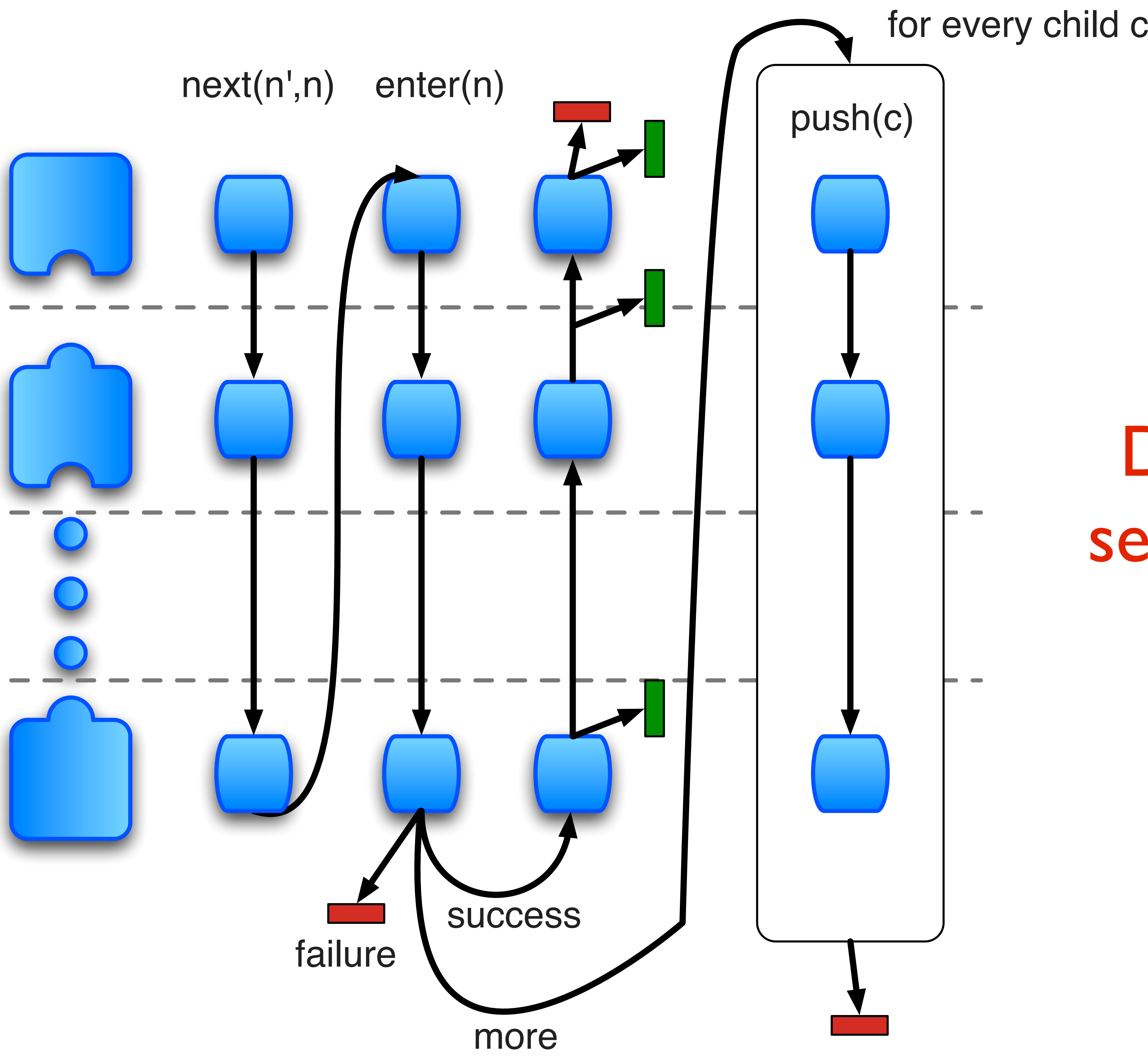
Functional Mixin Inheritance

- disciplined form of AOP
  - ★ meaningful and pre-defined set of interaction points
- no AOP system needed

Mixin-based Interaction



Mixin-based Interaction



Details: see paper

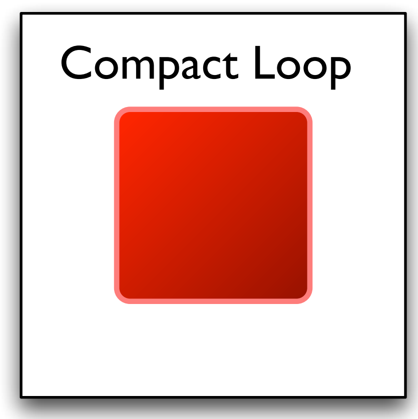
Implementations

DSL | **Haskell** | **C++**

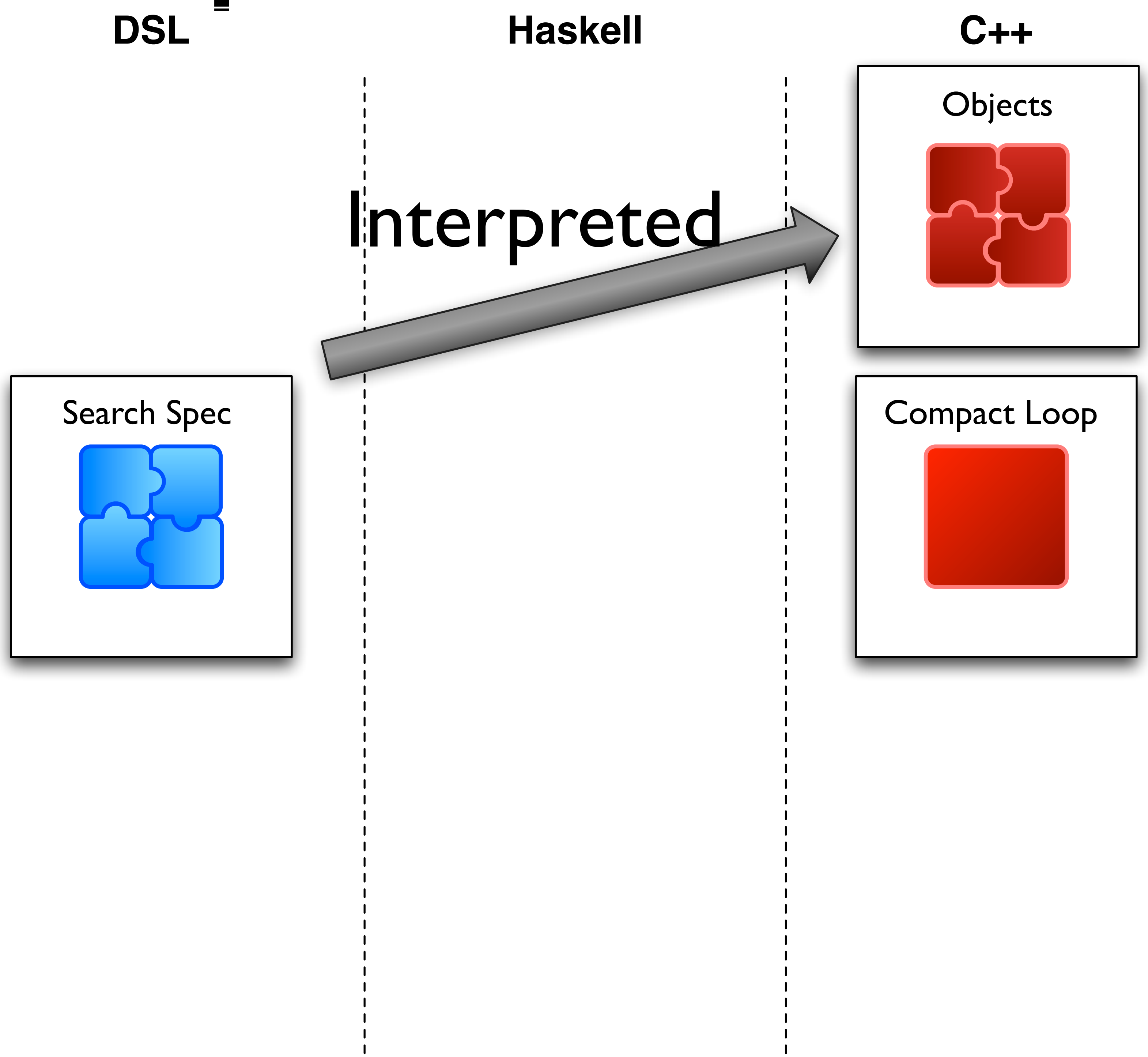
Compact Loop

Implementations

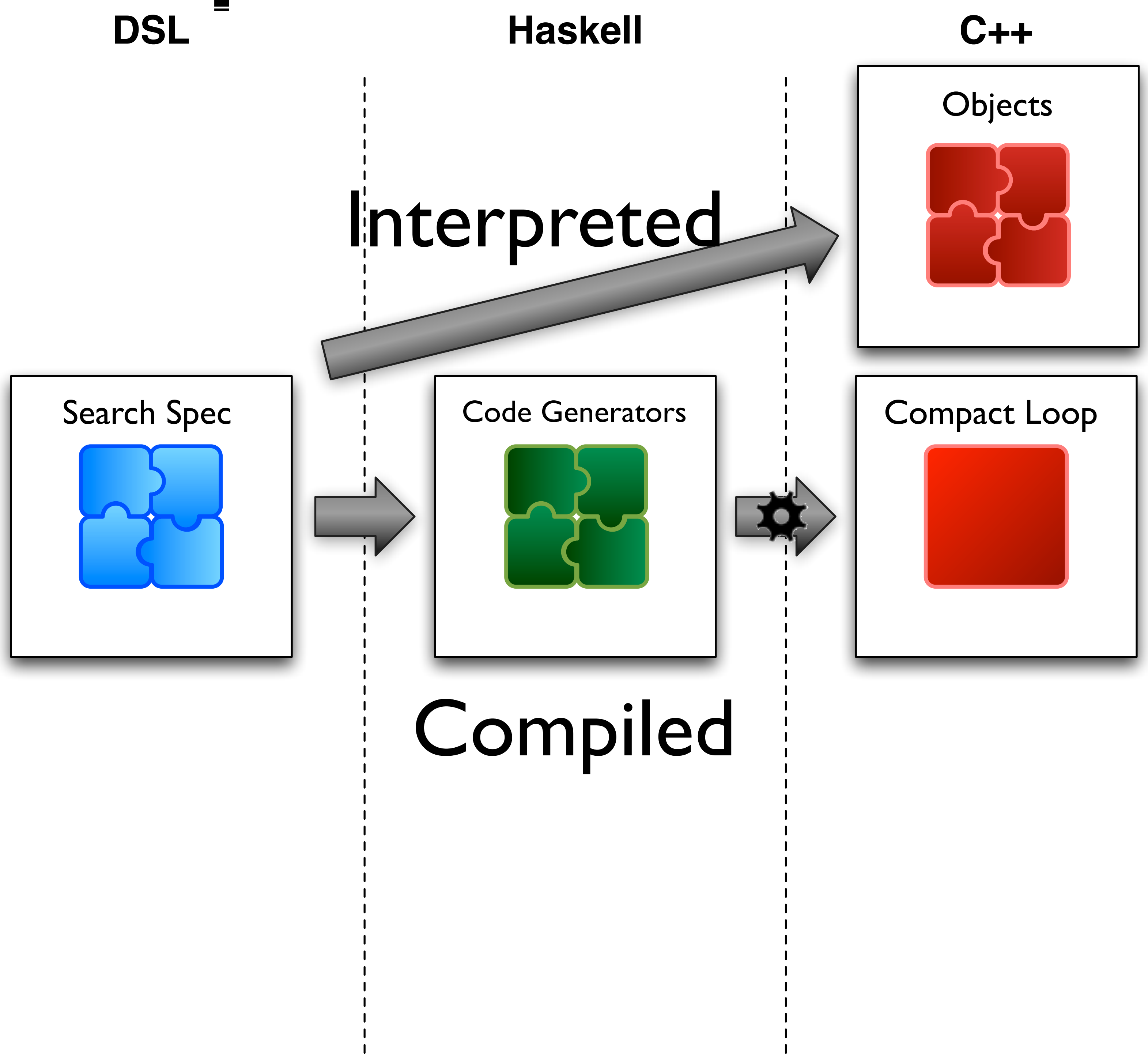
DSL | **Haskell** | **C++**



Implementations

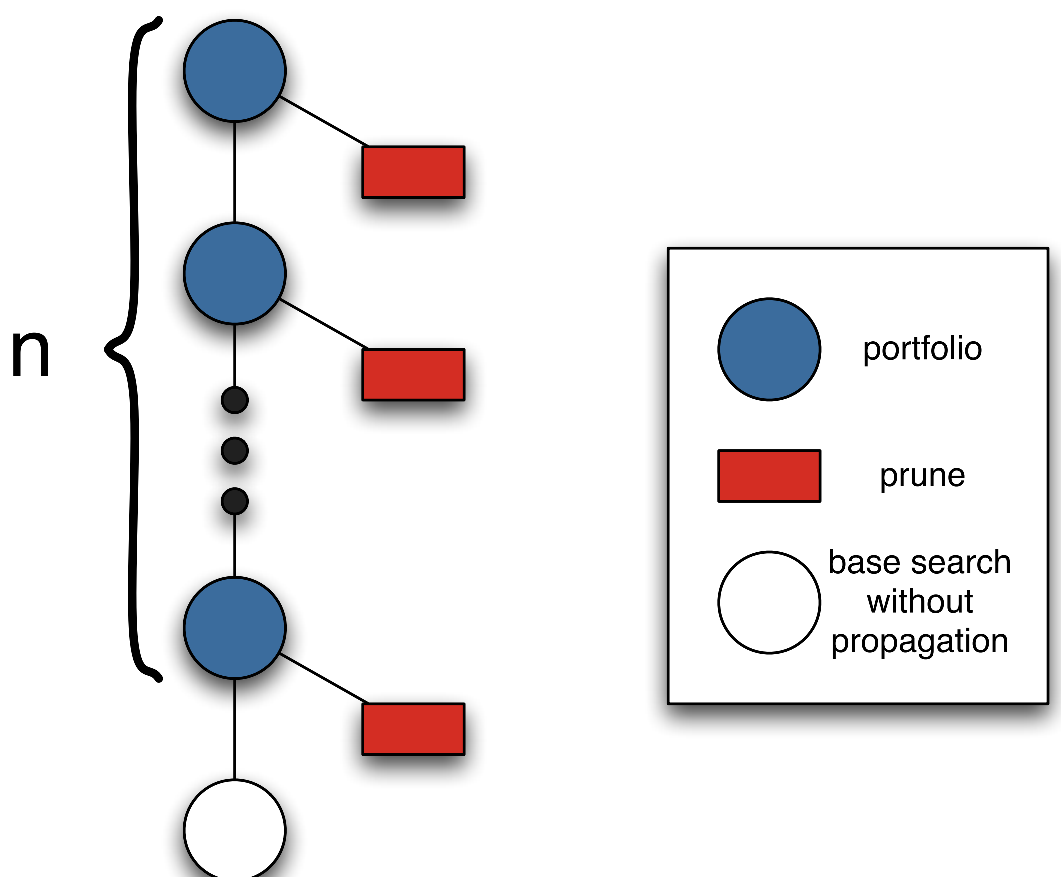


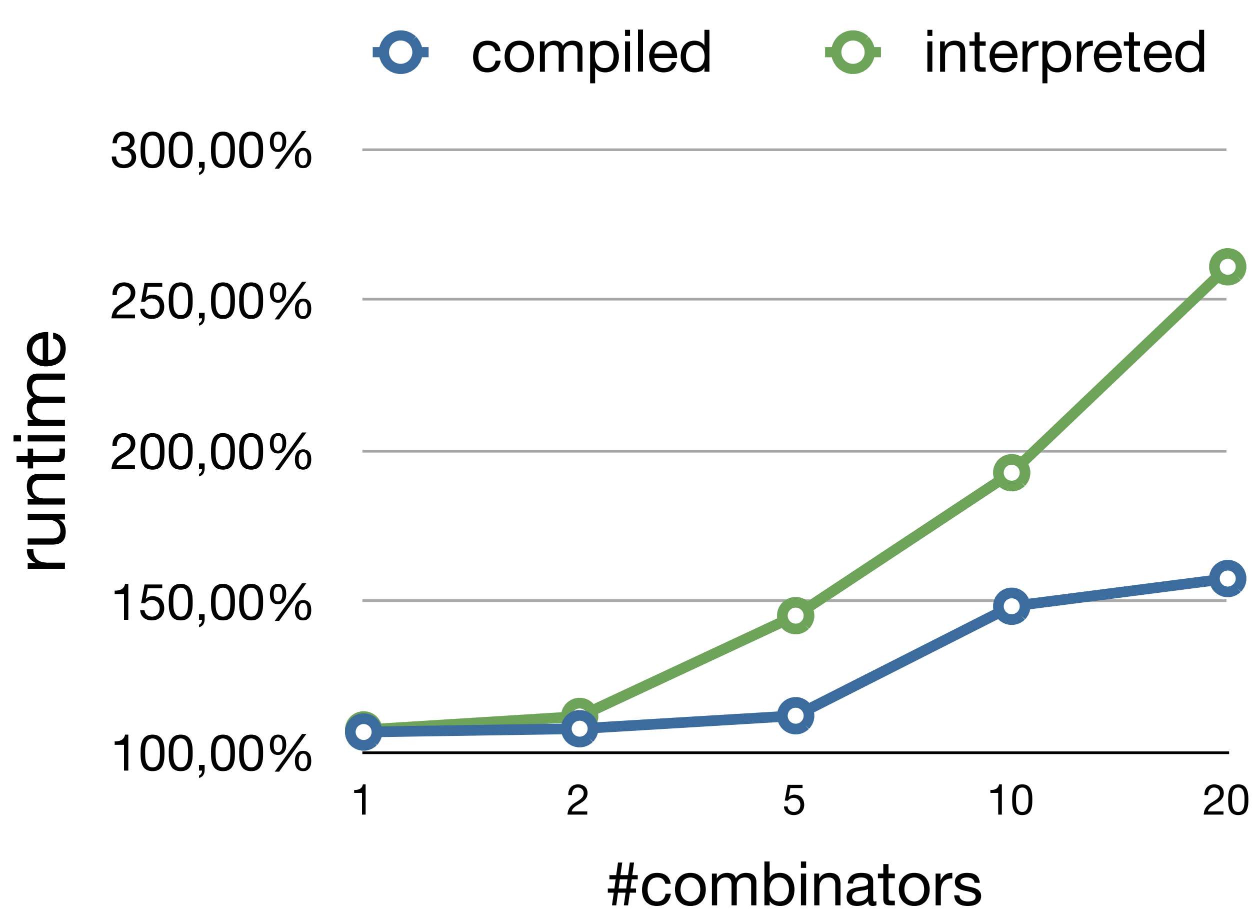
Implementations



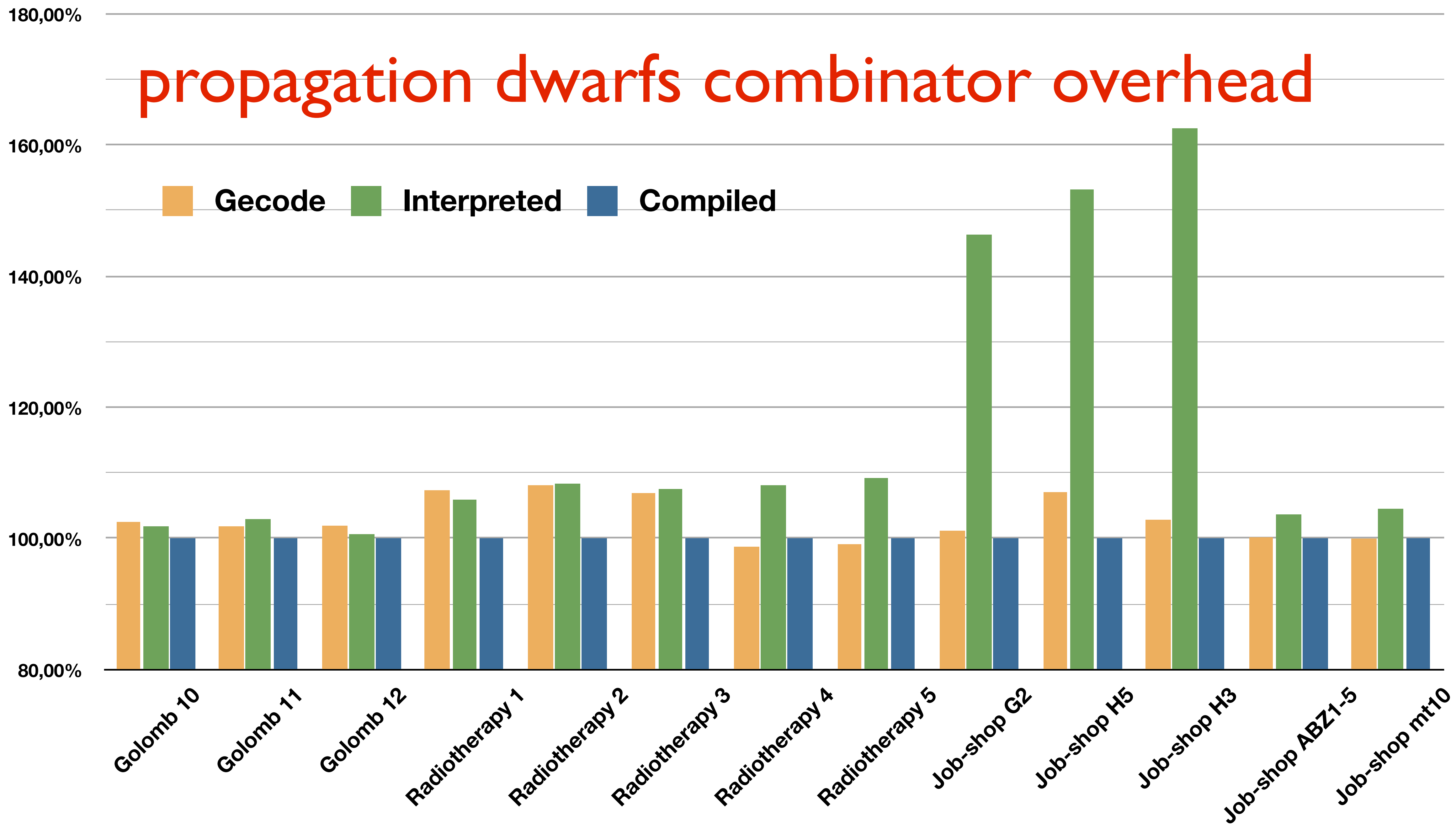
Combinator Overhead?

Worst-case Scenario





In Practice


180,00%
propagation dwarfs combinator overhead
160,00%
Gecode
Interpreted
Compiled
140,00%
120,00%
100,00%
80,00%
Golomb 10
Golomb 11
Golomb 12
Radiotherapy 1
Radiotherapy 2
Radiotherapy 3
Radiotherapy 4
Radiotherapy 5
Job-shop G2
Job-shop H5
Job-shop H3
Job-shop ABZ1-5
Job-shop mt10

Summary

- high-level modular modeling of search
- low-level modular implementation
- competitive performance compared to hand-coded algorithm

Future Work

- Optimizations
- MiniZinc integration
- Combinators for parallel search
- Extend other solving technology (e.g., LP)

➡ Combinators for hybrid search

Thank You!

Combinator Overhead