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Structured Traversal of Search Trees in Constraint-logic Object-oriented Programming

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Constraint-logic Object-oriented Programming

- Imperative/OO programming, combined with
- features from (constraint) logic programming

  $\Rightarrow$ Non-deterministic execution of imperative programs

Example, in “Münster Logic-Imperative Language” (Muli)

```
boolean flipCoin() {
  int coin free;
  if (coin == 0) return false;
  else return true; }
```

Motivation

- Branching $\rightsquigarrow$ Choice points $\rightsquigarrow$ Implicit search tree
- Depth unknown prior to execution
- Explicit structure facilitates: Search strategies, debugging, . . .

Structured Traversal of Search Trees

in Constraint-logic Object-oriented Programming

Constraint-logic Object-oriented Programming

Concepts

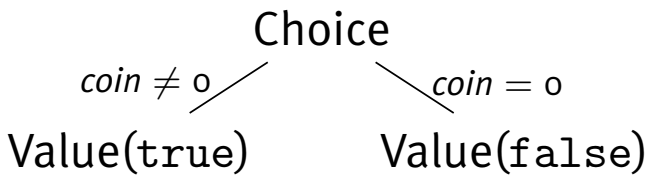
- Free variables (and fields) [DK18]

```
int y free;
```

- Constraints imposed by evaluating control structures

```
while (y > 5) { [...] }
```

- Non-deterministic execution in encapsulated search
- Search region written as lambda or Method Reference



- Implicit search tree, leaves are solutions (incl. exceptions)

Constraint-logic Object-oriented Programming

Muli Logic Virtual Machine

- Based on Muggl SJVM (test case generator), modified for Muli [MK11; DK18, DK19]
- Executes (Muli/Java) bytecode
- Execution state:

Frame stack	Operand stack	PC	Constraint stack	Choice point stack	Trails

- Non-deterministic branching $\Rightarrow$ choice point
- Choice point implementation
  - Previously: tracks choices and trails, controls execution
  - Now (Spoilers!): only declarative; MLVM in full control

Search Tree Representation

For comparison: Curry

[AHT19, BHH04]

```
x ? _ = x
_ ? y = y
```

e. g. `coin = 0 ? 1`

```
data ST a = Val a | Fail
          | Choice (ST a) (ST a)

Choice (Val 0) (Val 1)
```

In Muli

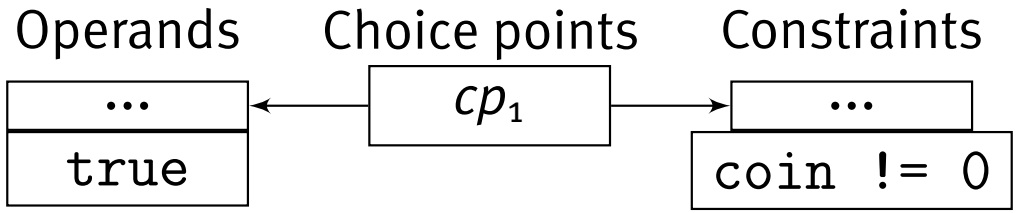
```
Muli.getAllSolutions( () -> {
  int coin free;
  if (coin == 0) {
    return false;
  } else {
    return true; } }
```

```
Solution[] {
  Solution(false), Solution(true) }
```

- additionally: single path on stack
- unstructured, transient

Search Tree Representation

Option: Implicit via choice point stack




```
Muli.getAllSolutions( () -> {
  int coin free;
  if (coin == 0) {
    return false;
  } else {
    return true; } }
```

Option: Explicit search tree

```
data ST a = Value a | Exception
          | Fail | Choice (ST a) (ST a)

Choice (Value false) (Value true)
```

Consider: Side effects ⇒ execution state!

Towards a Search Tree for CL-OO-P

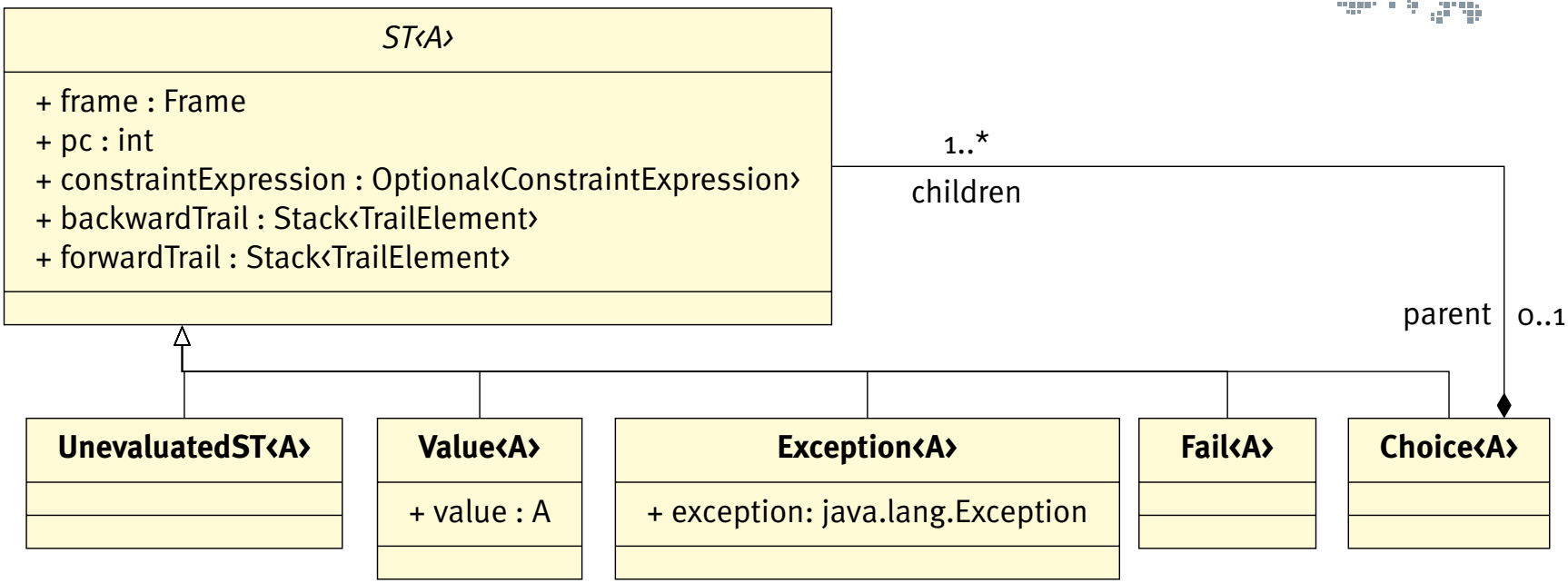
Types of choice

Triggering bytecode instruction	Type of choice	No. of decisions
`If<cond>`, `If_icmp<cond>`	`if` instruction, integer comp.	2
`FCmpg`, `FCmpl`, `DCmpg`, `DCmpl`	floating point comparison	2
`LCmp`	long comparison	3
`Lookupswitch`, `Tableswitch`	`switch` instruction	1 per case + 1

State

- Backtracking: return to former choice/state (e. g., operands and frame)
- Trails for navigation between choices
- During execution: Execute instruction with side-effect
  $\Rightarrow$ Push inverse of side-effect to backward trail
- During backtracking: Apply element from backward trail
  $\Rightarrow$ push inverse on forward trail

Search Tree Construction



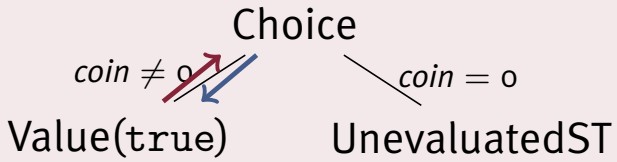
- New node ⇒ Return control to MLVM (every child is an `UnevaluatedST`)
- Non-strict evaluation
- Search strategies select next `UnevaluatedST`

```
Choice Uneval'dST Uneval'dST ⇝ Choice (Value false) Uneval'dST
```

Search Strategies

Primitives

- `navigateUpwards()`
- `navigateDownwards()`



- **BFS**

```
Choice
├─ Choice
│  ├─ UnevaluatedST
│  └─ UnevaluatedST
└─ Value(false)
```

- **DFS**

```
Choice
├─ Choice
│  ├─ Value(true)
│  └─ UnevaluatedST
└─ UnevaluatedST
```

Novel for (ND) imperative programs

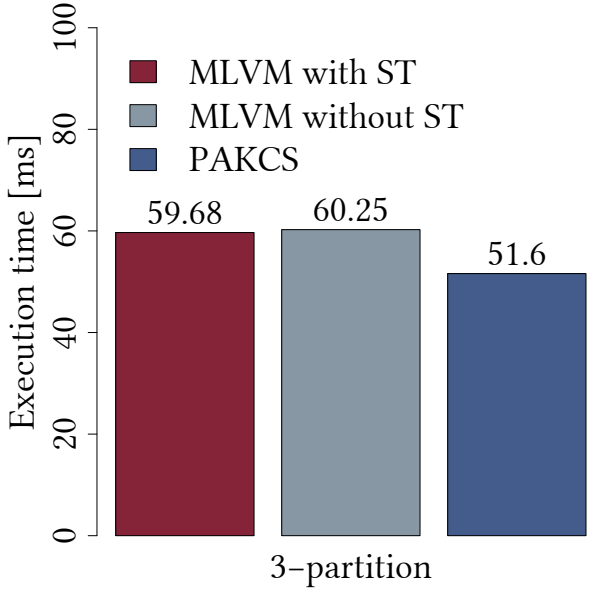
- **Iterative deepening DFS**

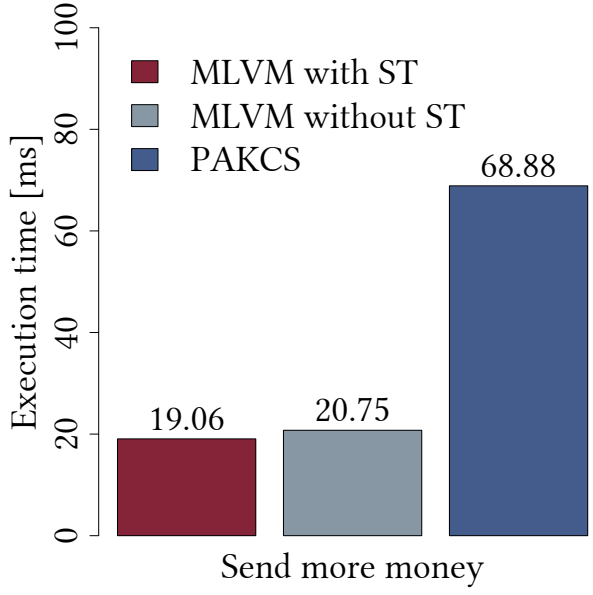
Key Results

- Useful for introspecting ND execution
- Foundation for complete search strategies
- Execution state changed:

Frame stack	Operand stack	PC	Constraint stack	Trails	Choice point stack
Frame stack	Operand stack	PC	Constraint stack	Trails	Search tree

- Increased memory requirements*, but performance unaffected





- *Optimisation: Purge trails of exhaustively evaluated subtrees

Concluding Remarks

Useful: Explicit structures (esp. in case of non-determinism)

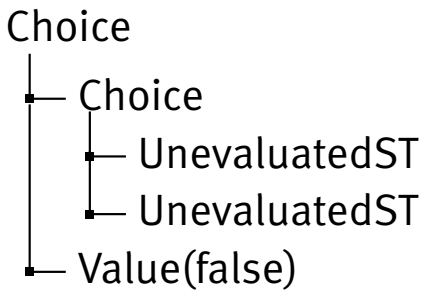
- Non-strict search tree representation
- Foundation for novel CL-OO search strategies
- Facilitates introspection

Implemented in MLVM, available on GitHub

- GPL, `https://github.com/wwu-pi/muli`

Future work

- Interactive search strategy
- Alternative representations



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