Viewpoints Research Institute

Research Summary: A Programming Methodology and A Reliability Mechanism

Hesam Samimi

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Viewpoints Research Institute, 1209 Grand Central Avenue, Glendale, CA 91201 t: (818) 332-3001 f: (818) 244-9761

Hesam Samimi
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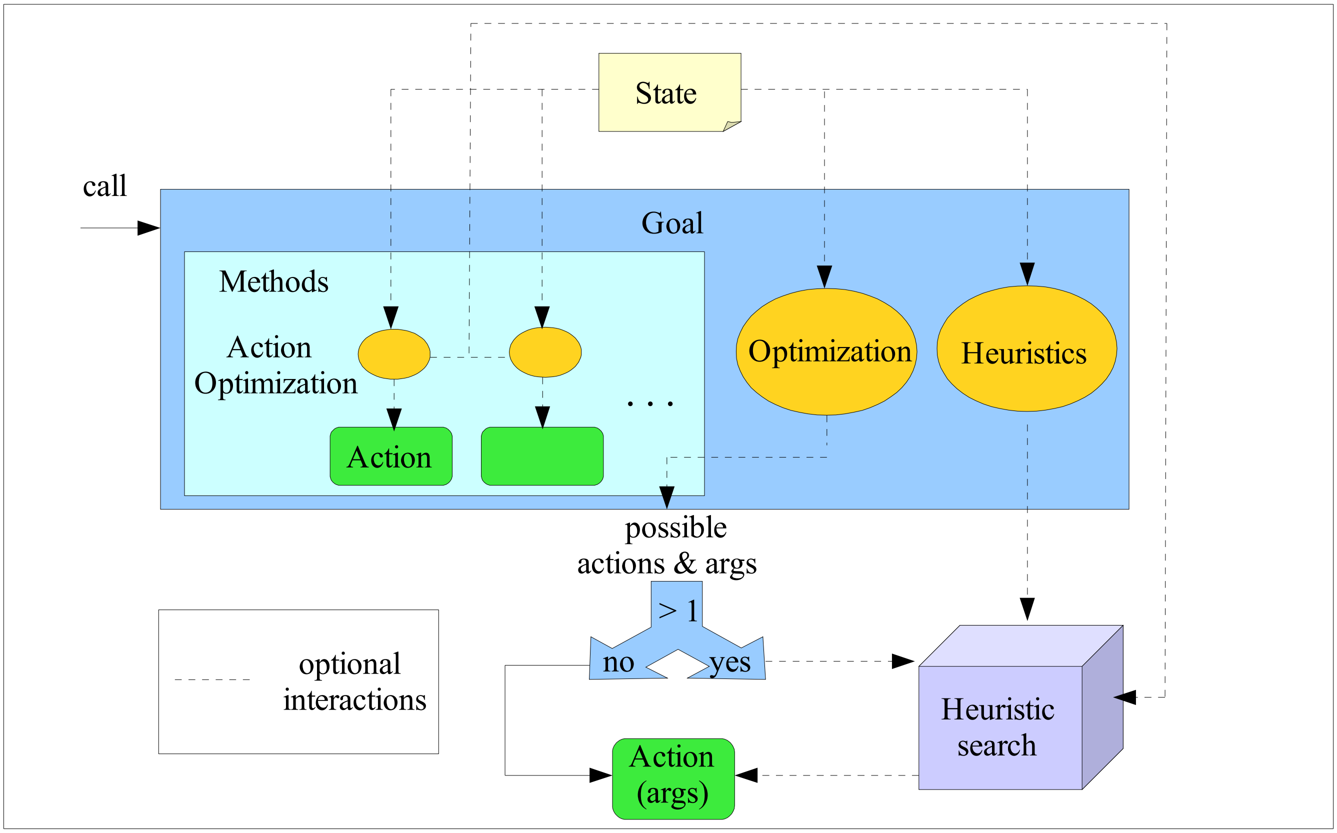
1. Programming as Planning

Programming tasks can be viewed from the AI viewpoint of automated planning. The meanings of programs (the declarative part) are considered *goals*, and the implementations (the imperative part) are *actions* that try to realize those goals. The planning problem is *optimizable* via heuristics that determine the right action (or set of plausible ones) to take at any given step in the execution. Our old friend— imperative program— is viewed as a *fully optimized* planning problem, where every action at every step of the program is predetermined. Effectively, the normal execution of an imperative program is traded for a higher level of control, which dynamically consults heuristics to determine the next instruction, or explore multiple possibilities by means of exhaustive search. The approach suffers from the overhead of a method call to determine the right dispatch at every step. On the other hand, it brings about the interesting possibility of non-deterministic computation by listing multiple actions to explore. *Optimizations* may be introduced to narrow down the possible actions to try at any given point, as well as *heuristics* that describe the preferred order in which to explore those possibilities.



Programming as Planning

The main advantage is that existing programs can adapt the methodology without much effort. A prototype extension of LLVM compiler was created that adapted the scheme to do optimal register allocation, a task reducible to graph coloring and NP-complete. The resulting register allocator program was substantially more compact and readable than the equivalent sections in the original C++ code.

```
Goal
allocation                         [ variables do:
                                      [:v | v isAssigned ifFalse: [^false] ].
                                     ^true ]
Goal Optimizations
allocation:optimization:           [ self haveRoomForNextVar ifTrue: [^#(assign:var:)].
                                     self spillRequired ifTrue: [^#(spill:)].
                                     ^#(split:to:) ]
Goal Heuristics
allocation:heuristic:              [ ^numSpills ]
Actions
assign: reg var: var               [ … ]
split: from to: to                 [ … ]
spill: var                         [ … ]
Action Optimizations
assign:var:optimization:           [ ^var = unAssignedVars first and:
                                       [ reg = nextAvailableWithLength: var length ] ]
```

Summary of AllocatorX86.st:
Programming-as-Planning in an Allocator Smalltalk program

```
{ john-program }

start-world allocatorx86.

;; CLASSES
create Allocator unallocated-variables.
create Variable length live-ranges.
create Register next-right allocations.

;; QUALIFICATIONS
qualify Word repeatn: N [ ] if N = 0.
qualify Word repeatn: N (its repeatn: (N - 1)) + it.
qualify Variable live-range [its live-ranges first first / 2, its live-ranges first
second / 2]. ;; fixme
qualify Variable repeatn: N [ ] if N = 0.
qualify Variable repeatn: N (its repeatn: (N - 1)) + it.
qualify Variable repeatList it repeatn: (its live-range second - its live-range first).
qualify Allocator next-variable its unallocated-variables first.
qualify Allocator next-variable-start its next-variable live-range first.

qualify Allocator canAllocate: Variable if
        for any all Register do each canAllocate: Variable = yes.
qualify Register allocationWith: Variable
        its allocations to: (Variable live-range first - 1) +
        Variable repeatList + its allocations from: (Variable live-range last).
qualify Register canAllocate: Variable if
        (Variable length = 2 or
       (not its next-right = no and
         for every Variable live-range do its next-right allocations at: each = empty)) and
        for every Variable live-range do its allocations at: each = empty.
```

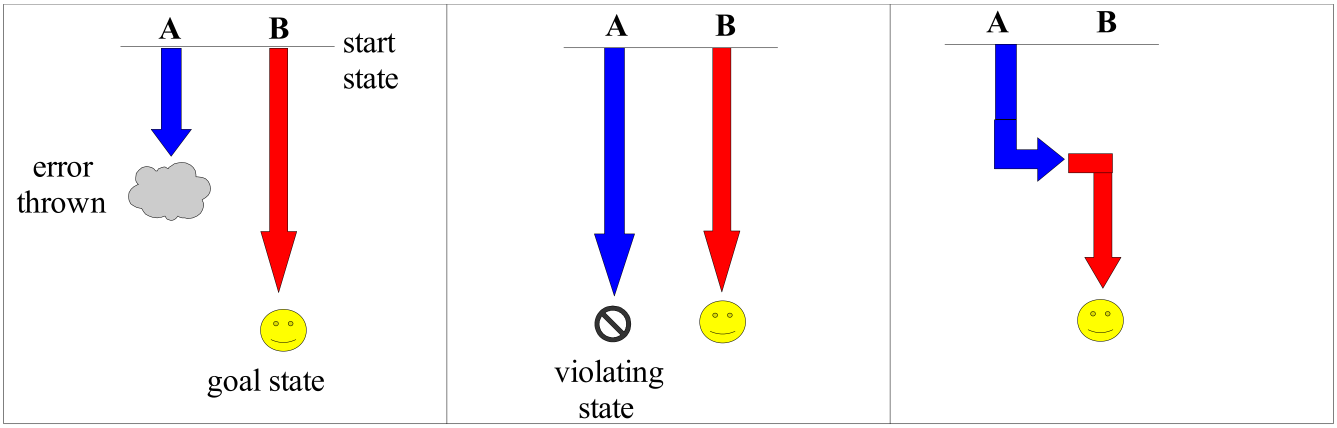
```
;; ACTIONS
action Allocator assign Register Variable consequence
       Register allocations = Register allocationWith: Variable and
       Register next-right allocations = (Register next-right) allocationWith: Variable if
Variable length = 4 and
       its unallocated-variables = its unallocated-variables rest.

rule Allocator assign is Register canAllocate: Variable = yes.

action Allocator split Register:RegisterFrom Register:RegisterTo consequence
       RegisterTo allocations = RegisterTo allocations to: (its next-variable-start - 2) +
                                RegisterFrom allocations from: (its next-variable-start -
1) and
       RegisterFrom allocations = RegisterFrom allocations to: (its next-variable-start -
2) +
                                  empty repeatn: (RegisterFrom allocations size - (its
next-variable-start - 2)).
rule Allocator split is not RegisterFrom = RegisterTo.
rule Allocator split is not RegisterTo = RegisterFrom next-right.
rule Allocator split is not (RegisterFrom allocations at: (its next-variable-start)) =
empty.
rule Allocator split is RegisterFrom allocations at: (its next-variable-start) length = 2.
rule Allocator split is RegisterTo allocations at: (its next-variable-start - 2) = empty.

;; GOALS
goal Allocator allocation try its unallocated-variables size = 0.

;; OPTIMIZATIONS
action-optimization Allocator assign dynamically establish Variable = its next-variable.
action-optimization Allocator assign dynamically establish Variable length = 2 or not
Register next-right = no.
goal-optimization Allocator allocation use split if it canAllocate: (its next-variable) =
no.
goal-optimization Allocator allocation use assign if it canAllocate: (its next-variable) =
yes.

;; OBJECTS
for [ [ "Va" name, 2, [ [ 2, 22 ] ] ], [ "VB" name, 4, [ [ 6, 14 ] ] ], [ "Vc" name, 2, [ [
10, 18 ] ] ], [ "Vd" name, 2, [ [ 14, 22 ] ] ], [ "VE" name, 4, [ [ 18, 22 ] ] ] ] do make
Variable (each first) (each second) (each third).
for [ ["R1" name, "R2" name], ["R2" name, no], ["R3" name, "R4" name], ["R4" name, no] ] do
make Register (each first) (each second) (empty repeatn: 12).
make Allocator Al (all Variable).

Al satisfy allocation.

end-world.
```

The Allocator program written in planning language JOHN

2. Executable Specifications

Our study shows formal specifications can realize an instance of Marvin Minsky's B brains visions. He proposed a system with multilevel control logic, where the higher levels, say B brain, may take over the control, or affect the execution of the normal logic, the A brain. One can view meanings and specifications as B brains, and normal implementations as A brains. We observed three scenarios where the declarative specifications may want to take over the implementations 1. Accidentally due to a run time error 2. Accidentally due to the implementations failing to satisfy the specifications (post-conditions) 3. Intentionally where implementations explicitly yield the control to the specifications to save lines of code, avoid complex corner cases, etc.

🟦 A brain: Implementation
🟥 B brain: Specifications



Three scenarios for implementation to specifications fallback

The specifications, which cover global class invariants as well as post-conditions for methods, are usually expressed in high level syntax involving first-order logic expressions. It is desirable for the specifications to be written in same language as the rest of the program, so that they can be run and tested like normal methods. Thus syntactic sugars may be supported for these expressions, including quantified expressions, as well as field closures useful for recursive data structures. But support for high-level expressions in the specifications is not just a matter of providing more readable and mathematical formed code. Such expressions carry the semantics necessary to enable translating them into formulas in the syntax of constraint solvers. In the event of a fallback to meanings, we use external constraint solvers to extract a satisfying model to the problem expressed in the specifications and apply the model to the object.

A *Binary Search Tree* program is shown below with *insert* and *delete* methods in the Java language extended with the high-level function methods. The two operations are fully runnable without any implementations, only relying on the specifications accompanying them denoted with the *ensures* keyword. The .^ and .* symbols denote reflexive and non-reflexive field closures and .< is a map field-get over a set of objects.

```
public class BSTree
    ensures isAcyclic() && oneParent() && isValidBinarySearch()
{
    …
    function public ESJSet<Node> nodes() { root.*(left+right) }
    function public ESJSet<Integer> nodeValues() { this.nodes().<value }
    function public boolean isAcyclic() { no Node n | n.descendants().contains(n) }
    function public boolean oneParent() {
      (root == null) ?
         true :
         all Node n : this.root.^(left+right) | one Node p | n.parent == p
    }
    function public boolean isValidBinarySearch() {
       all Node n |
        ((n.left == null  || all Node lc : n.left.*(left+right)  | lc.value < n.value) &&
         (n.right == null || all Node rc : n.right.*(left+right) | rc.value > n.value))
    }
    public void insert(Node insertedNode)
      modifies BSTree.root, Node.left, Node.right, Node.parent
      ensures this.nodes().equals(this.old.nodes().union(insertedNode)) {
      // no implementation...
    }
    public void delete(Integer key)
      modifies BSTree.root, Node.left, Node.right, Node.parent
      ensures this.nodeValues().equals(this.old.nodeValues().minus(key)) {
      // no implementation...
    }
```

A fully runnable Binary search tree program with insert and delete operations, only relying on specifications