Tag-based Modularity in Tree-based Genetic Programming

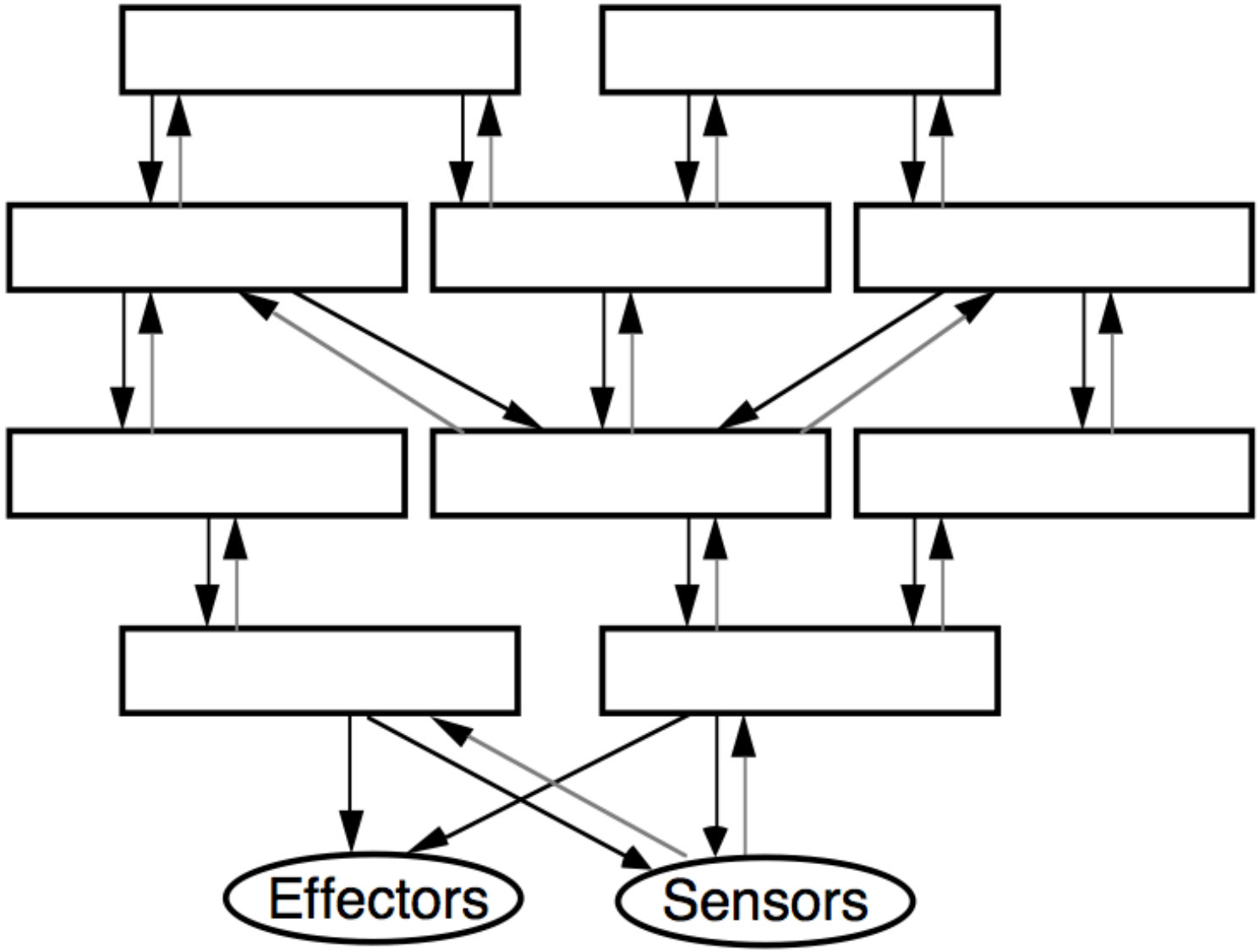
Lee Spector, Kyle Harrington & Thomas Helmuth

Cognitive Science, Hampshire College
Computer Science, Brandeis University
Computer Science, University of Massachusetts, Amherst

Outline

- Evolving modular programs
- Tags
- Evolving tag-based modules in PushGP
- Can we do the same thing in tree-based GP?
- Experiments and Conclusions
- Prospects

Modularity is Everywhere



Modules in GP

- Automatically-defined functions (Koza), macros (Spector)
- Architecture-altering operations (Koza)
- Module acquisition/encapsulation systems (Kinnear, Roberts, many others)
- Modules in GE (Swafford et al., others)
- In Push: code-manipulation instructions that build/execute modules as programs run

ADFs

- All programs in the population have the same, pre-specified architecture
- Genetic operators respect that architecture
-
```
(progn (defn adf0 (arg0 arg1) ...)
       (defn adf1 (arg0 arg1 arg2) ...)
  (.... (adf1 ...) (adf0 ...) ...))
```
- Complicated, brittle, limited...
- Architecture-altering operations: more so

Tags

- Roots in John Holland's work on principles of complex adaptive systems
- Applied in models of the evolution of altruism, with agents having tags and tag-difference thresholds for donation
- A tag is *an initially meaningless identifier that can come to have meaning through the matches in which it participates*
- Matches may be inexact

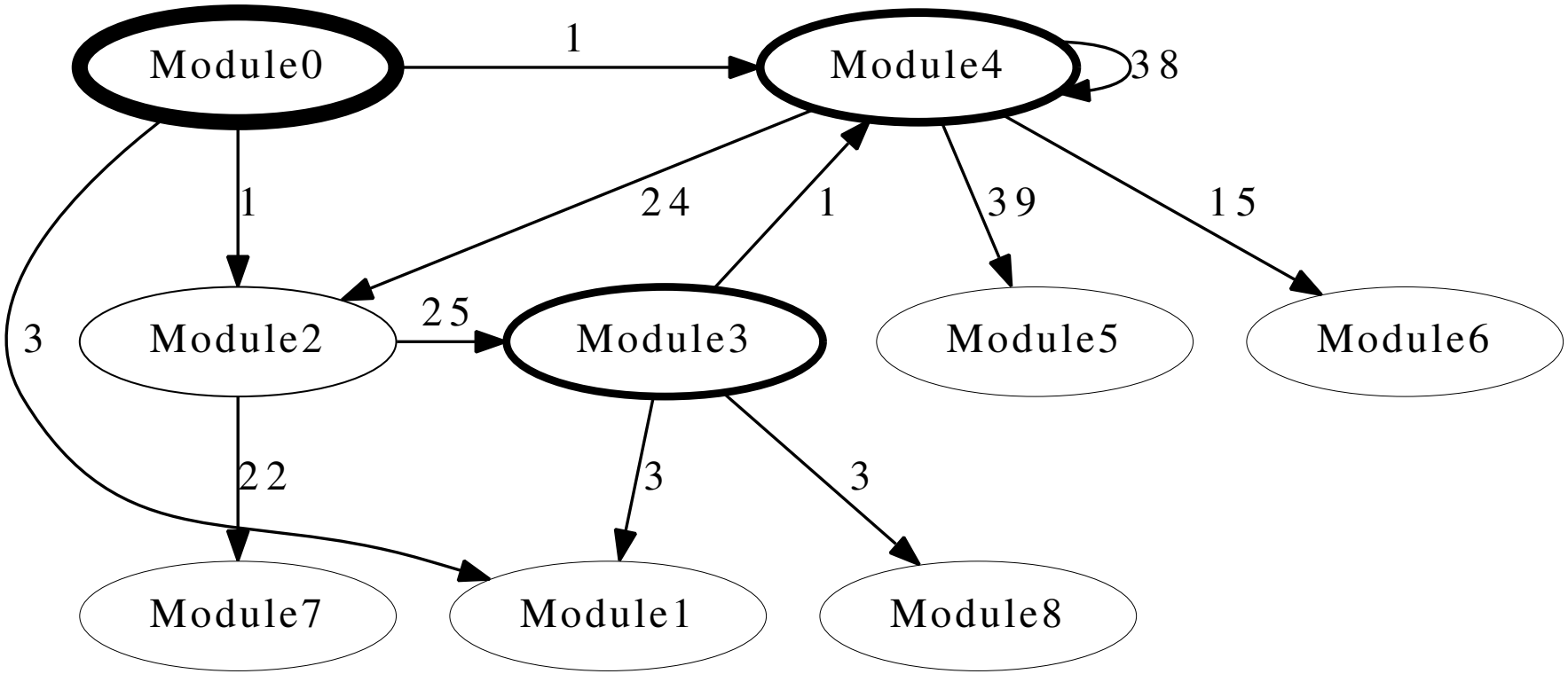
Tag-based Modules in GP

- Add mechanisms for tagging code
- Add mechanisms for retrieving/branching to code with closest matching tag
- As long as any code has been tagged, all branches go somewhere
- Number of tagged modules can grow incrementally over evolutionary time
- We use integer tags and unidirectional difference with wraparound for inexact matching

Push

- Stack-based postfix language with one stack per type
- Types include: integer, float, Boolean, name, code, exec, vector, matrix, quantum gate, [add more as needed]
- Missing argument? NOOP
- Trivial syntax:
  program → instruction | literal | (program*)

Evolved DSOAR Architecture (in one environment)



Prior Conclusions

- Execution stack manipulation supports the evolution of modular programs in many situations
- Tag-based modules are more effective in complex, non-uniform problem environments
- Tag-based modules may help to evolve complex software and solutions to unsolved problems in the future

Tags in S-Expressions

- A simple form:
  `(progn (tag-123 (+ a b)) tagged-034)`
- Challenges:
  - Endless recursion
  - Return values (of tagging and of tag references prior to tagging)
  - Arguments, particularly of multiple types
  - Multiple return values from modules

Endless Recursion

- Here we enforce an execution step limit and (generally) penalize programs that exceed it
- In Push results may be available even when execution is terminated for hitting the limit

Return Values

- Of tagging: we consider:
  - "silent": return default constant value without executing tagged code
  - "non-silent": evaluate the tagged code and return its value
- Of tag references prior to tagging: here we return a default constant value
- In Push it is trivial to provide *no* return value in all of these cases

Arguments

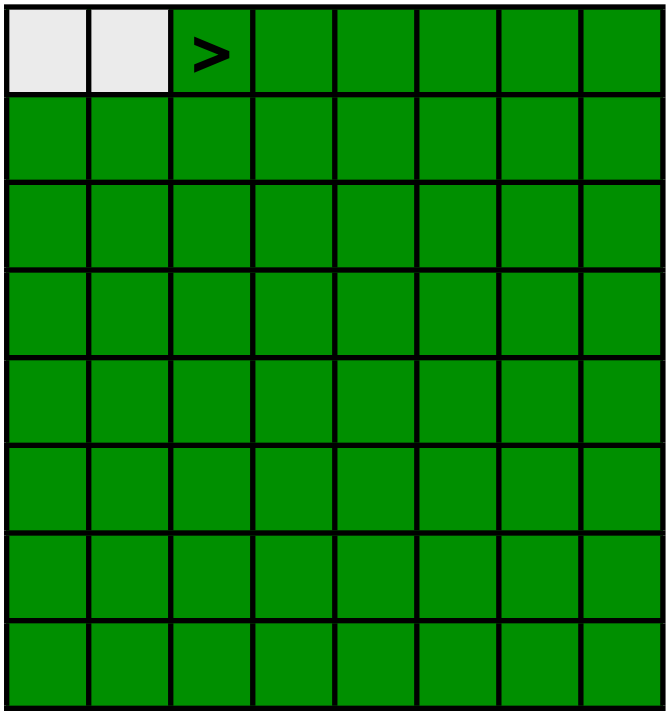
- Here we allow only 0-argument modules
- There's a tricky way in which the tag space itself can *conceivably* be used to pass arguments anyway (see paper)
- In Push any number of arguments may be provided without doing anything special

Multiple Return Values

- Basically we ignore this here, although again the tag space could *conceivably* be used to do something similar
- In Push it is trivial to return any number of values

Lawnmower Problem

- Used by Koza to demonstrate utility of ADFs for scaling GP up to larger problems



Lawnmower Results

Table 2: Results of genetic programming in several conditions related to tagging on the lawnmower problem.

Tags	Silent	No-op	Successes	MBF	Effort
No	—	No	63	0.45	282,000
No	—	Yes	53	0.62	357,000
Yes	No	—	97	0.13	30,000
Yes	Yes	—	65	0.57	144,000

Even 4-Parity Results

Table 4: Results of genetic programming in several conditions related to tagging on the even-4-parity problem.

Tags	Silent	No-op	Succ	MBF	Effort
No	—	No	58	0.56	234,000
No	—	Yes	36	1.02	495,000
Yes	No	—	22	1.44	950,000
Yes	Yes	—	19	1.61	1,044,000

First Conclusion

- The very simple form of "tags in trees" considered here is not always good!
- The remainder of our paper considers less simple approaches that may be better

Unbounded Recursion

- Penalties for hitting the execution limit may make tags too "dangerous"
- Note: we did not use penalties for the Lawnmower problem, since it works by side effects on the lawn state
- Various approaches are possible for *eliminating* rather than penalizing unbounded recursion

Arguments

- Pseudo-argument symbols like **`arg0`**, **`arg1`**, etc., which get replaced by values passed in as arguments to argument-taking tag-reference functions like **`tagged-1-arg`**, **`tagged-2-arg`**, etc.
  - Defaults for args in wrong contexts
  - Pre-specify maximum number of args
- Tag references with embedded argument reference tags

Program Size and Depth

- In the simple scheme presented here, tagging and tag references increase tree size and depth
- Depth and size limits therefore punish tag usage
- Tagging and tag-reference calls can be omitted from counts/limits in various ways
- Alternative syntax may involve less impact on size and depth

More Conclusions

- Trees are constraining!
- Tags may nonetheless be useful in tree-based GP
- Everyone should use Push ;-)
- Tag-based modules may also be a good fit to other forms of GP, e.g. Cartesian GP and Grammatical Evolution

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