

Utilization of Reductions and Abstraction Elimination in Typed Genetic Programming

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Presentation outline

- Types & lambda calculus : Why to use them in GP?
- Related work
- Generating and reductions
- Crossover operators for lambda terms : problems with local variables
- Experiment

Types in GP

- Types help us overcome the *closure requirement*.
 - No longer need for “everything fitting into everything”.
- But they also establish new requirements
 - e.g. function arguments must obey type requirements...
 - These requirements make the programs more reasonable,
 - and reduce the search space.

Lambda calculus

- Simple yet powerful (mathematical) *functional programming* language
- It uses anonymous functions very often.
- Roughly speaking:

s-expressions + anonymous functions = lambda calculus



λ *<var-name>* . *<body-expr>*

aka

function(<var-name>){ return <body-expr>; }

x may occur in this subtree...

Benefits of using Functional programming for GP

- Complex and/or general programming constructs can be described as higher-order functions
 - Example: **foldr** function for implicit recursion
 - Another view: generalized for cycle
 - Body of *for cycle* corresponds to anonymous function given to *foldr* as argument.
- Types provide rigorous way to talk about (sub)programs and to enforce constraints.

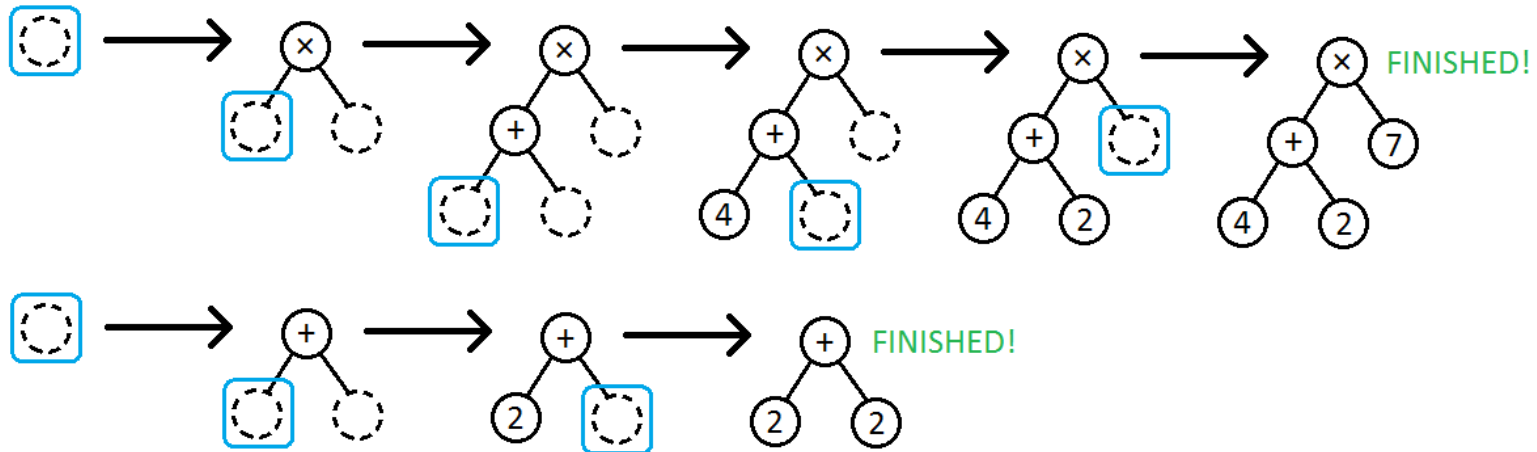
Related work

- Yu : PolyGP
 - uses lambda term representation, but restricts the use of outer local variables in the body of an anonymous function.
 - Hindley-Milner type system
- Briggs and O'Neill : Purely combinator approach
 - purely combinator approach
 - no anonymous functions, no local variables
 - Hindley-Milner type system
- Binard and Felty
 - Even stronger type system (System F) → non-standard algorithm
 - Genes (i.e. subtrees) have fitness

Our approach to typed GP over lambda calculus

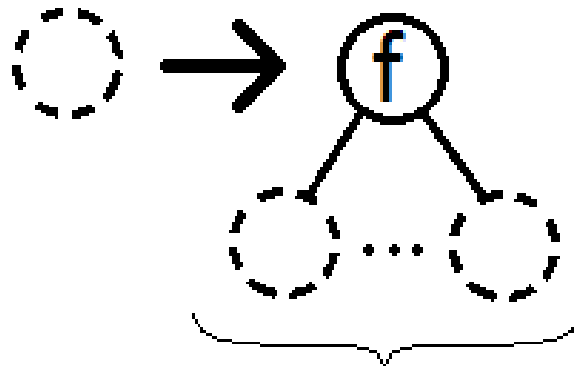
- Simple type system (Simply typed lambda calculus)
 - with future generalizations in mind (H-M, H-M with type classes)
- ..but complete generating
- Anonymous functions
- Generalization of the standard GP

Tree generating terminology



- ***Expansion***

- In each step an *unfinished node* is replaced by a more specific tree:



0 or more unfinished nodes for subtrees

Local context (aka Γ)

- Set of symbol names accompanied with types
- “ $\mathbf{T} \cup \mathbf{F}$ is an initial/global context”
- We can add local variables to a context

Expansions for Simply typed lambda calculus

	No types	Types, no contexts	Simply typed lambda calculus	
Unfinished node	\circ	α	$\tau \mid \Gamma$	
Expansion(s)		<p> $f : \underbrace{\tau_1 \rightarrow \dots \rightarrow \tau_n}_{\text{inputs types}} \rightarrow \underbrace{\alpha}_{\text{ouput type}}$ </p>	<p><i>atomic types:</i></p> <p> $(f : \tau_1 \rightarrow \dots \rightarrow \tau_n \rightarrow \alpha) \in \Gamma$ </p>	<p><i>function types:</i></p> <p> $(\lambda x. \sigma) \in \Gamma$ </p>

Generating and reductions

- *Reduction*: transformation of one term into another

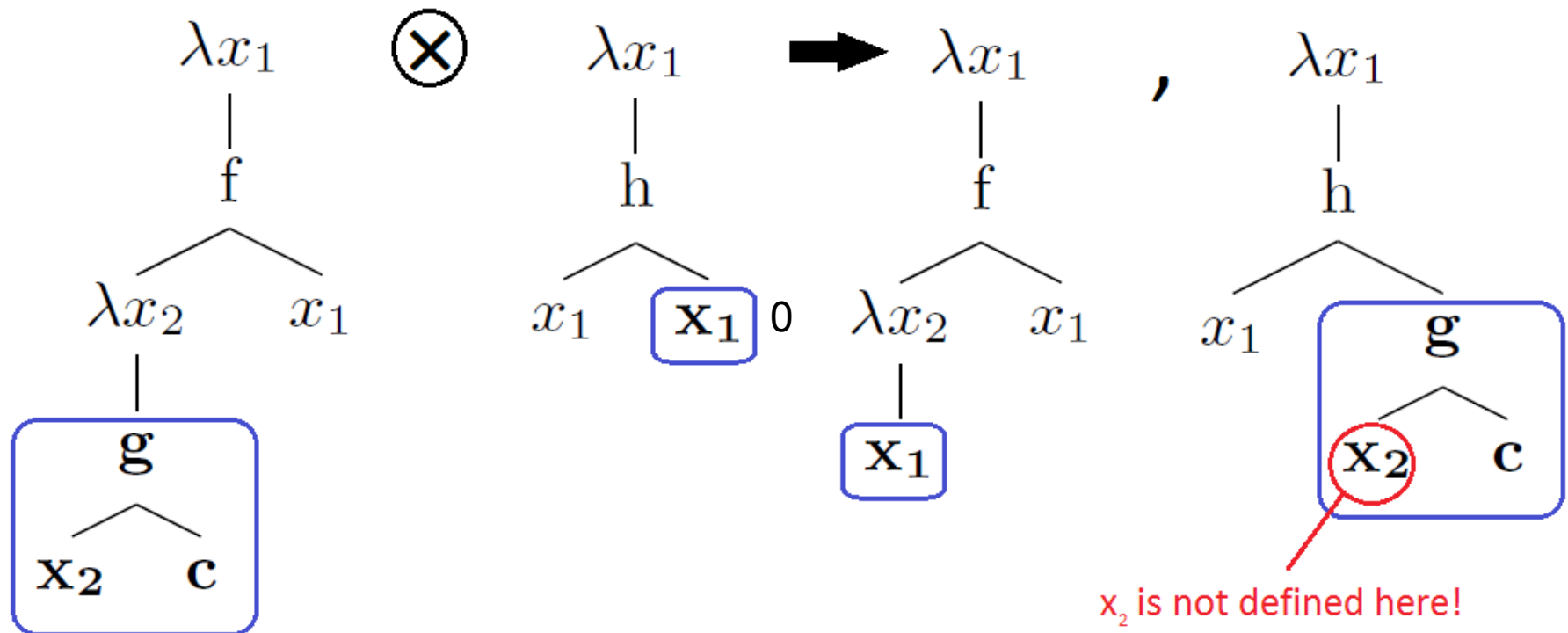
beta reduction: $(\lambda x . M)N \rightarrow_{\beta} M[x := N]$

eta reduction: $(\lambda x . (M \ x)) \rightarrow_{\eta} M \quad \text{if } x \notin FV(M)$

- From *reduction* arises notion of *term equivalence* (relative to that reduction)
- *Normal form*: term that can't be further reduced
- Described method generates *long normal form (Inf)*
 - Each *Inf* term represent whole *beta-eta-equivalence class*
 - **This reduces the search space**

Crossover operator for lambda terms

- Generalization of simple tree swapping crossover
- We need to swap subtrees with a same type
 - ..but that is simple
- Local variables cause the trouble!



Abstraction elimination

- An algorithm for getting rid of local variables and anonymous function
 - **Input:** an arbitrary lambda term
 - **Output:** equivalent S-expression that may contain additional new function nodes **S**, **K** and **I** which are defined as:

$$S = \lambda f g x . f x (g x)$$

"function(f,g,x){ return f(x, g(x)) }"

$$K = \lambda x y . x$$

i.e. "function(x,y){ return x }"

$$I = \lambda x . x$$

"function(x){ return x }"

Hybrid crossover

- Each generated term is transformed by abstraction elimination
- All terms are typed S-expressions
- So now we only need to swap subtrees with the same type
- *Hybrid* because
 - lambda term representation during generation phase
 - Advantage: reduced search space during generation phase
 - Pure combinator representation during the rest
- Possible disadvantage: up to quadratic increase in term size

Unpacking crossover

- All terms are kept in small $\beta\eta$ -normal form
- ...and transformed right before crossover
- After the tree swapping both children are again normalized
- So the quadratic increase is only temporary

Experiment

- We compare performance of *hybrid* and *unpacking* crossover.
- Even parity problem
 - Similar function and terminal set as in *PolyGP* by T. Yu

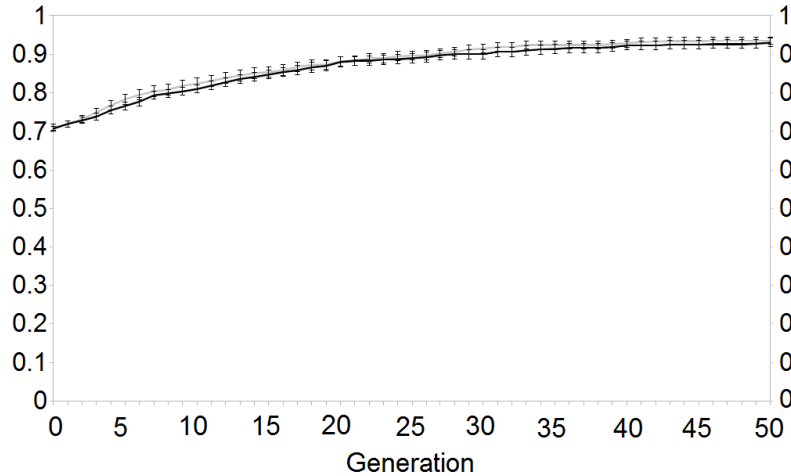
$$\boxed{\tau_0 \quad \Gamma_0}$$

$$\tau_0 = [Bool] \rightarrow Bool$$

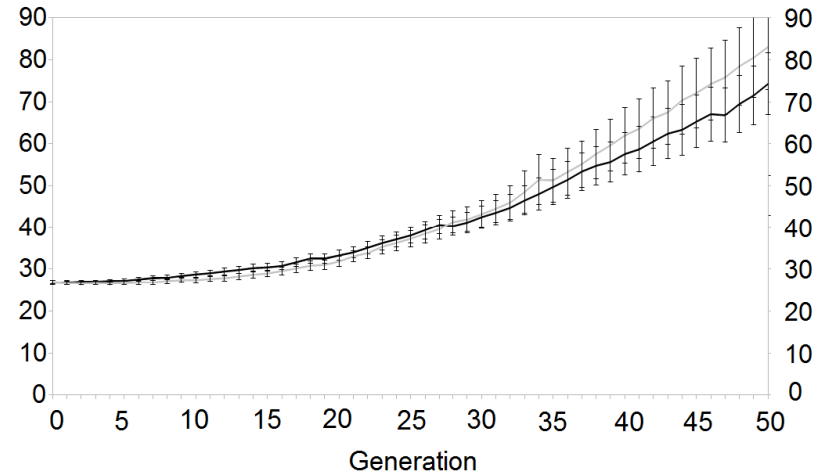
$$\begin{aligned} \Gamma_0 = \{ & and : Bool \rightarrow Bool \rightarrow Bool, \\ & or : Bool \rightarrow Bool \rightarrow Bool, \\ & nand : Bool \rightarrow Bool \rightarrow Bool, \\ & nor : Bool \rightarrow Bool \rightarrow Bool, \\ & foldr : (Bool \rightarrow Bool \rightarrow Bool) \\ & \quad \rightarrow Bool \rightarrow [Bool] \rightarrow Bool, \\ & head' : [Bool] \rightarrow Bool, \\ & tail' : [Bool] \rightarrow [Bool] \} \end{aligned}$$

Results

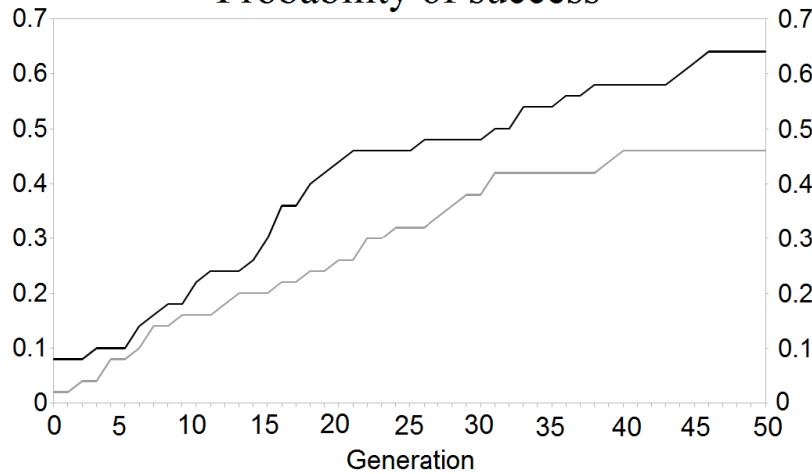
Fitness of the best individual



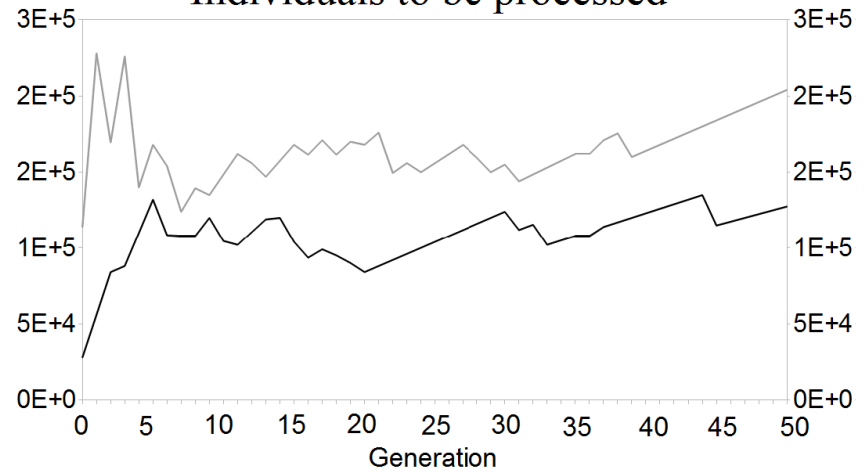
Average term size



Probability of success



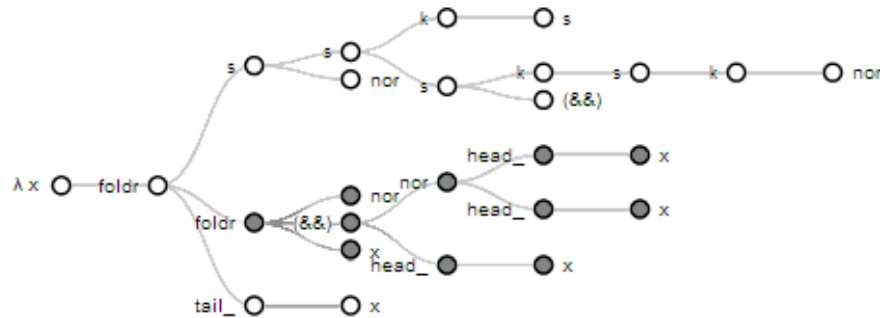
Individuals to be processed



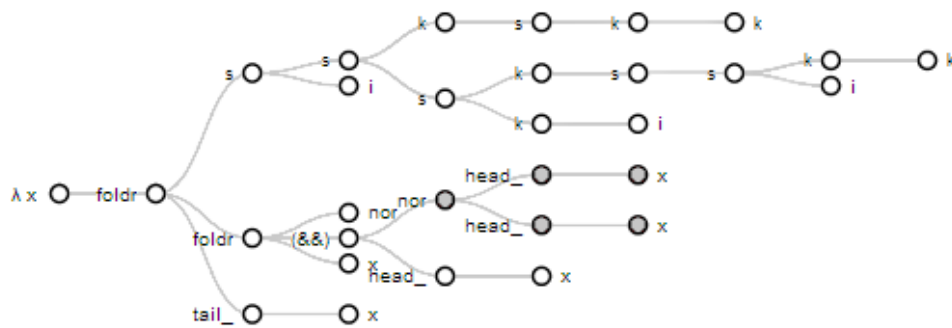
Unpacking crossover
Hybrid crossover

Times: **388** minutes
33 minutes

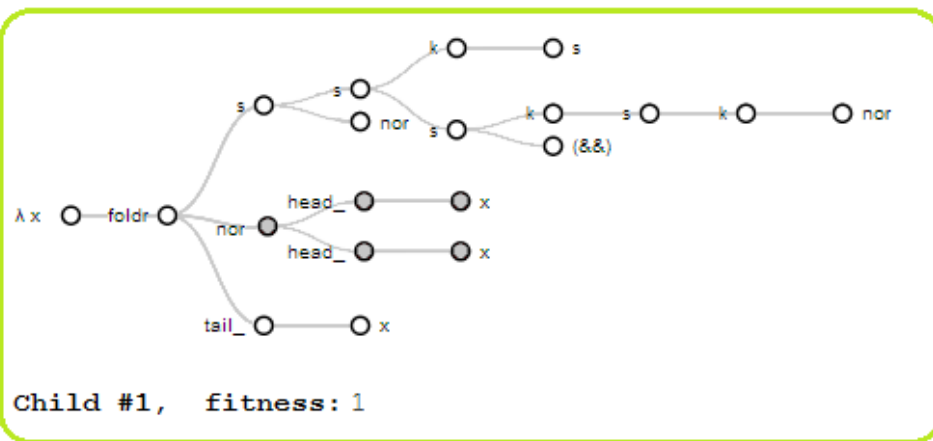
Results



Parent #1, fitness: 0.8125



Parent #2, fitness: 0.5



$$\lambda x . foldr (\mathbf{S}(\mathbf{S}(\mathbf{K} \mathbf{S})(\mathbf{S}(\mathbf{K}(\mathbf{S}(\mathbf{K} \text{ nor}))))\text{and}))\text{nor}) \\ (\text{nor} (\text{head}' x) (\text{head}' x)) (\text{tail}' x)$$

$=_{\beta\eta}$

$$\lambda x . foldr (\lambda y z . \text{nor} (\text{and } y z) (\text{nor } y z)) \\ (\text{nor} (\text{head}' x) (\text{head}' x)) (\text{tail}' x)$$

Which is equivalent to:

$$\lambda x . foldr \text{ xor } (\text{not} (\text{head}' x)) (\text{tail}' x)$$

GP approach	$I(M, i, z)$
PolyGP	14,000
Our approach (hybrid)	28,000
GP with Combinators	58,616
GP with Iteration	60,000
Our approach (unpacking)	114,000
Generic GP	220,000
OOGP	680,000
GP with ADFs	1,440,000

Results comparison

Conclusions

- How to generate lambda terms in *Inf*
 - Why? It reduces search space
- How to crossover terms containing local variables using abstraction elimination technique
 - Hybrid vs. Unpacking : Hybrid wins
- Future work
 - More experiments
 - More elaborate analysis (Price's covariance for crossover,...)
 - Stronger type systems (H-M, H-M with type classes)

Thank you for your attention!

Any questions?

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