Direct Manipulation of Abstract Syntax Trees

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Theodore S. Norvell

Computer Engineering Research Labs, Dept. ECE, MUN

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This talk is about two things

- Keeping software *simple* and *robust*.
  - **Small details matter!!**
- Making the user experience *pleasant* and *efficient*.
  - **Small details matter!!**

There is nothing difficult or advanced here.
And that's the point.
A few key decisions make the bulk of the work straightforward.
And the software robust and reusable.

Trees are everywhere.

I think that I shall never see,
a structure lovely as a tree.
With root aloft and leaves aground,
for nature's trees are upside-down.

- Programs are trees
- File systems are trees
- Documents are trees
  - HTML
  - XML

How do we make a good user experience for entering and editing trees?

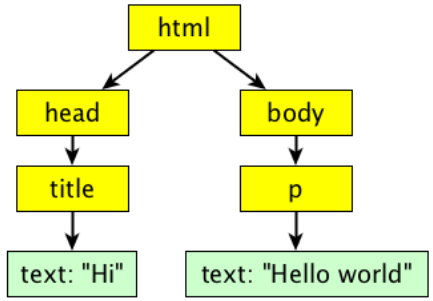
The context

- I've been working on a visual programming language: PLAAY.
  - *Low threshold:* Should be easy for beginners to use.
  - *High ceiling:* Should be useful to professionals.
- In PLAAY syntax errors can not be made because:
  - The user edits the program by directly manipulating the abstract syntax tree.
  - The editor only permits valid abstract syntax trees.
  - This is good for beginners *and* professionals.

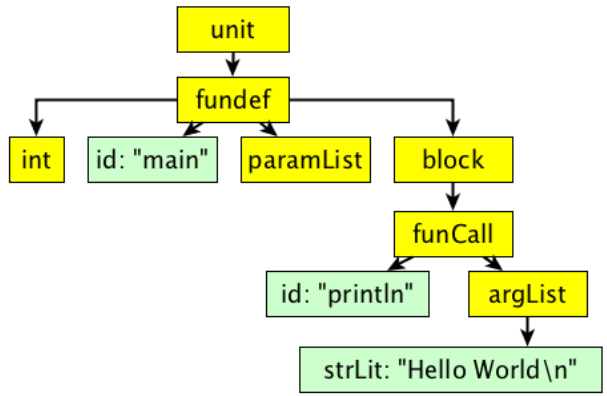
Trees

- A tree is consists of
  - A label.
    - Typically consists of a tag or kind possibly some other information such as a string or a boolean
  - A sequence of 0 or more shorter trees.

```
<html><head><title>Hi</title></head><
body><p>Hello world</p>
```



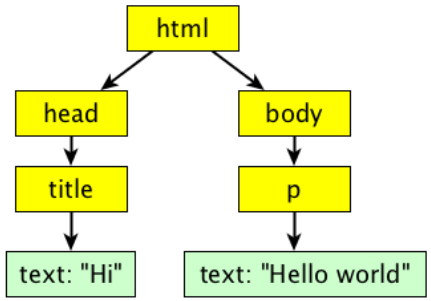

```
int main() { println("Hello world\n") ; }
```

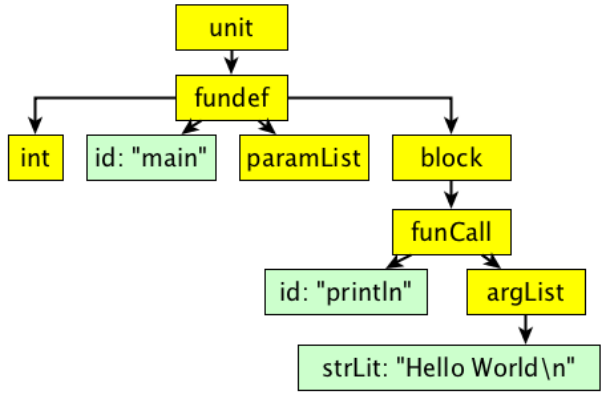


Valid Trees

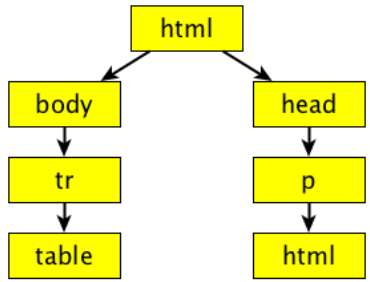
Not all trees are valid.

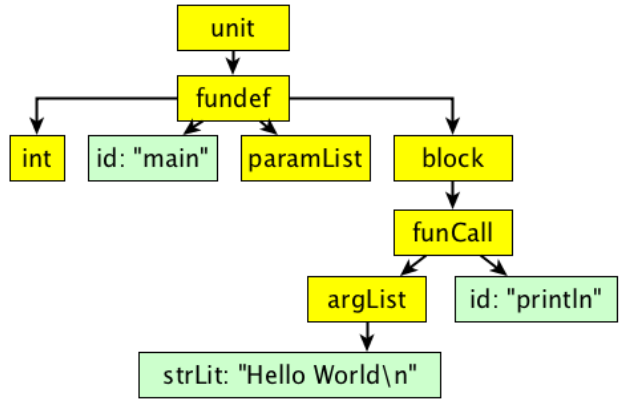
- Valid trees





- Invalid trees





Trees that are valid for a given language we say are within the *abstract syntax* of the language.

Editing Valid Trees

- User interface cycle:
  1. t := some valid tree
  2. display t to the user
  3. wait for a UI event
  4. attempt to make a new valid tree
  5. if successful: t := the new tree ; go to 2
  6. else: go to 3
- *Validity is a loop invariant!*

Representing trees

Three key decisions

- Make it impossible to build an invalid tree.
- Make it impossible for tree to become invalid.
- *Validity is a data invariant!*
- Use Options to deal with failure

Representing trees

The classes

All labels must have a boolean method that determines whether or not it can be used with a given list of children.

```
interface PLabel {
    public isValid(children : Array<PNode>) : boolean;
    ...  }
```

An example `PLabel` class:

```
class WhileLabel implements PLabel {
  public isValid(children : Array<PNode>) : boolean {
    return children.length === 2 &&
      children[0].isExprNode() &&
      children[1].isExprSeqNode() ; } ... }
```

Representing trees

The classes

There is one class of nodes

```
class PNode {
  protected _label: PLabel ;
  protected _children:Array<PNode>;
  ... }
```

Representing trees

The truth

- Actually the `PLabel` and `PNode` classes are specializations of generic classes called `DLabel<L,N>` and `DNode<L,N>`.
- This allows us to reuse much of the code for other applications:
  - HTML editors
  - LaTeX editors
  - Generic XML editors
- For the sake of this presentation, I'll ignore the genericity. See the paper for details.

Representing trees

First key decision

It is impossible to make an invalid tree.

```
class PNode {
  protected _label: PLabel;
  protected _children:Array<PNode>;
  constructor( label:PLabel,
               children:Array<PNode>) {
    assert.check( label.isValid(children),
       "Attempted to make invalid tree.");
    this._label = label;
    this._children = children.slice(); } ... }
```

The first line of the constructor will throw an exception if we try.

Representing trees

Second key decision

It is impossible for an existing tree to become invalid.

- This is enforced by making the PNode class *immutable*.
- And all classes that implement PLabel must be *immutable*.

Consequences

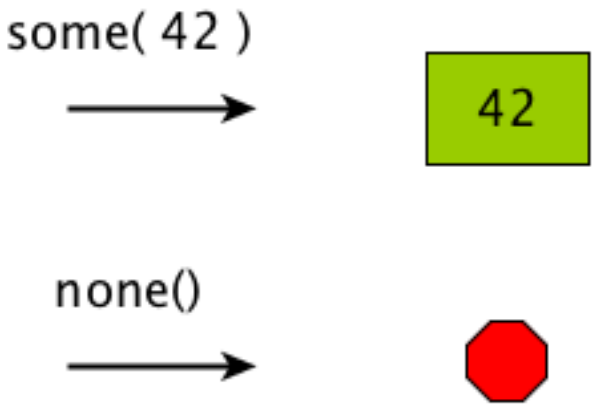
- Immutability permits sharing. Trees are represented by DAGs.
- Changes are functions from trees to trees
- In short we use functional programming w.r.t. trees.

Digression on the Option type

Type `Option<number>` represents numbers that might be absent. There are two kinds of option objects.

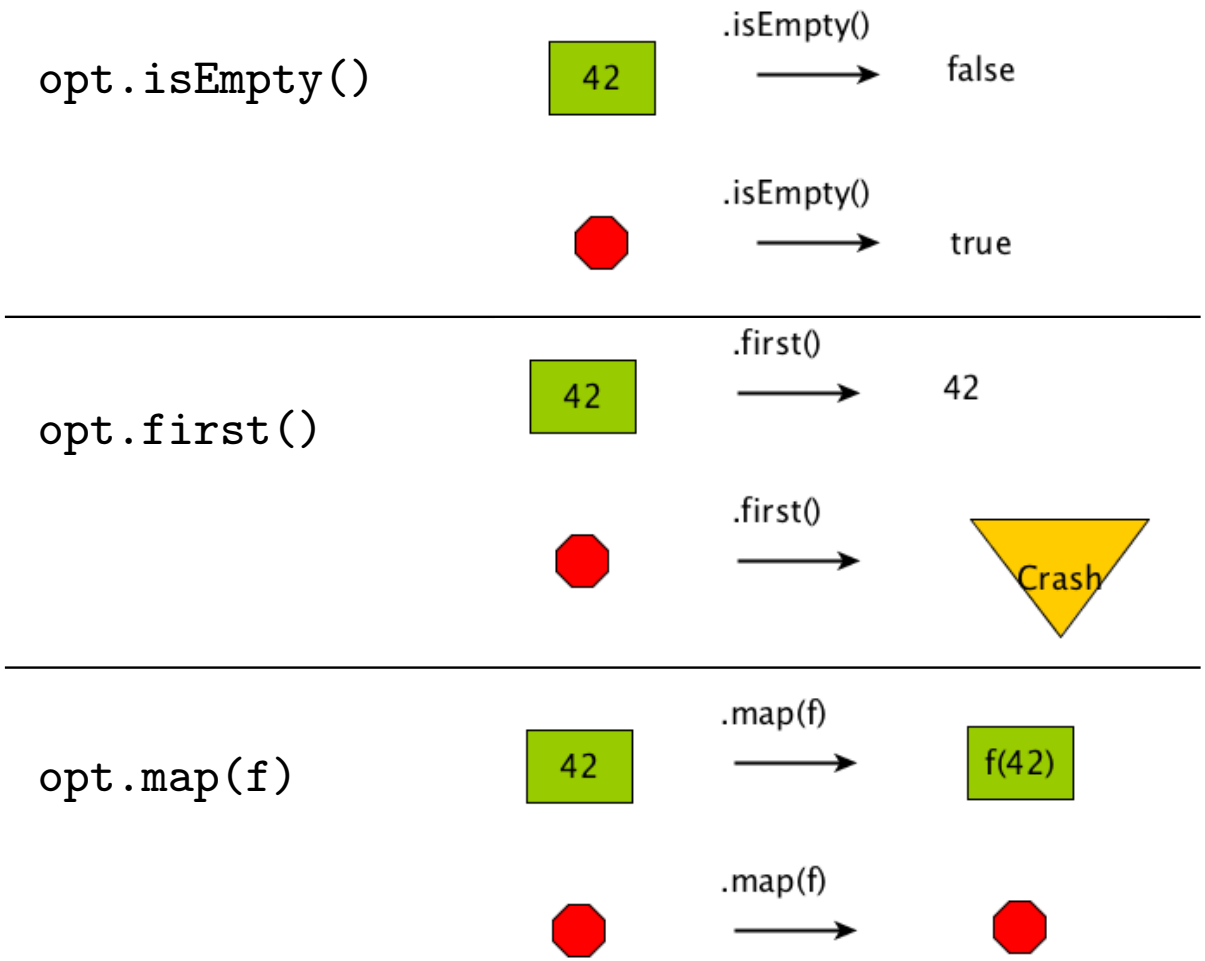
- `some<number>(42)` – The value 42, wrapped in a box
- `none<number>()` – Is a lump of coal. I.e. no number.

Think of an `Option<T>` object as a collection of 1 or 0 objects of type `T`.



Digression on the Option type

Operations on `Option<T>` objects.



Representing trees

Third key decision

Use Options

- Throwing exceptions from constructors does not promote robustness unless we either
  - *ensure they are always caught and handled* or
  - *ensure they are never thrown*
- We do the latter.

Rather than directly calling `PNode`'s constructor we call `tryMake`

```
function tryMake( label:PLabel,
                  children:Array<PNode> )
    : Option<PNode> { ... }
```

which returns `none()` if the desired tree would be invalid.

The caller of `tryMake` must either deal with either outcome or must return an option.
For example:

```
const opt = tryMake(label, children);
return opt.map( newNode =>
                    new Selection( newNode, ... ) );
```

where `none().map(f) = none` and `some(x).map(f) = some( f(x))`. So this code returns an `Option<Selection>`. It passes the buck.

Another example:

```
const opt = paste( dragged, dropTarget ) ;
opt.map(sel => updateDisplay( sel ) );
```

Here the code does nothing if the option is empty. Otherwise it updates the display.
It is not impossible to screw up with options, for example I could have written

```
const opt = paste( dragged, dropTarget ) ;
update( sel.first() );
```

Recall `none().first()` crashes.
Failing to catch an exception is a *sin of omission*.
It is easy to make and hard to spot.
But using `first` instead of `map` is a *sin of commission*.
Any use of `first()` should set off alarm bells for the design reviewer.

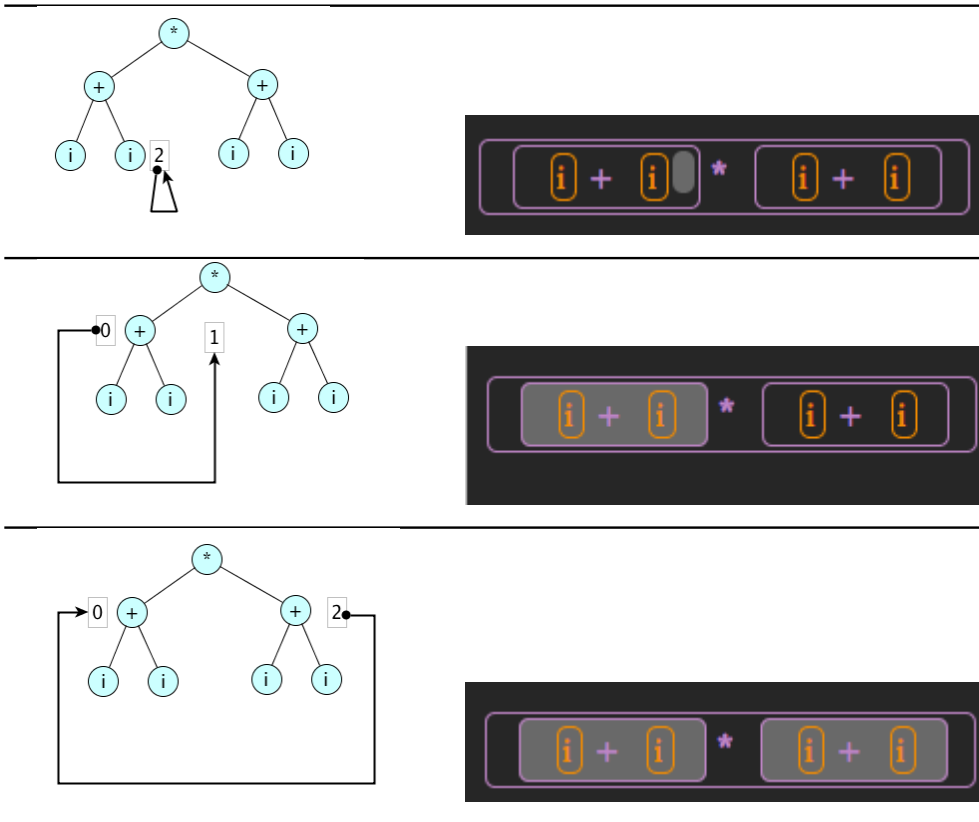
Selections

Fourth key decision: Use a simple selection model.

A selection consists of

- A PNode called the *root*
- A *path* in the tree
- A number called the *anchor*
- A number called the *focus*

Selections are *immutable*



Edits

Fifth key decision: Use a "little language" of edits.

An `Edit` maps each `Selection` to an `Option<Selection>`

- An `Edit` object represents a partial function

Composition of edits: If

$$h = f \circ g$$

then

$$\begin{aligned} h(x) &= f(x) \text{ if } f(x) \text{ is empty} \\ h(x) &= g(f(x).\texttt{first}()) \text{ otherwise} \end{aligned}$$

Biased choice of edits: If

$$h = f \oplus g$$

then

$$\begin{aligned} h(x) &= f(x) \text{ if } f(x) \text{ is not empty} \\ h(x) &= g(x) \text{ otherwise} \end{aligned}$$

Edits

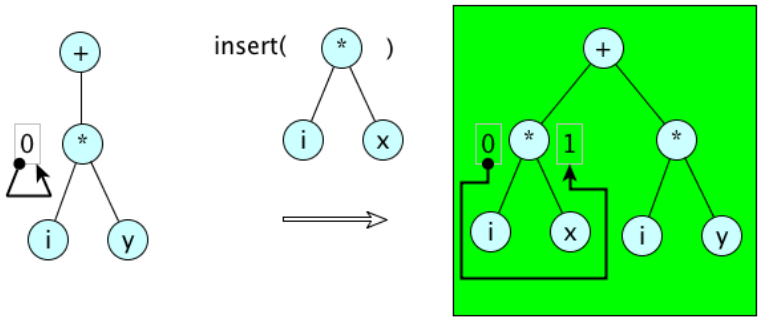
Assuming termination and no-side effects, edits form a simple algebra (two laws short of a semiring)

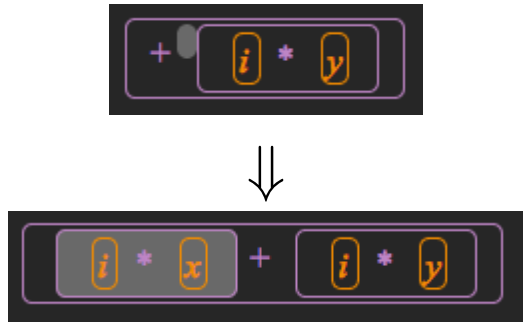
$$
\begin{aligned}
(f \oplus g) \oplus h &= f \oplus (g \oplus h) \\
0 \oplus f &= f \\
f \oplus 0 &= f \\
(f \circ g) \circ h &= f \circ (g \circ h) \\
1 \circ f &= f \\
f \circ 1 &= f \\
f \circ (g \oplus h) &= (f \circ g) \oplus (f \circ h) \\
0 \circ f &= 0 \\
f \circ 0 &= 0
\end{aligned}
$$

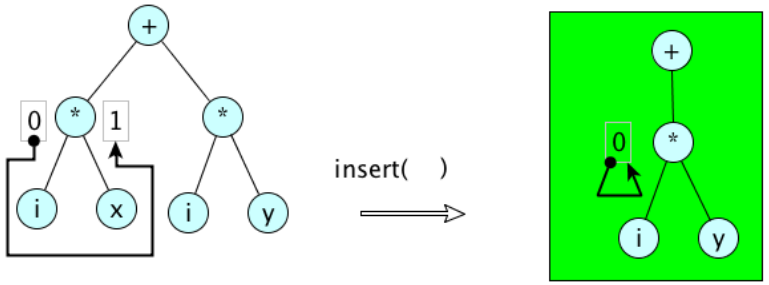
Where 1 is the identity edit and 0 is the edit that always fails.

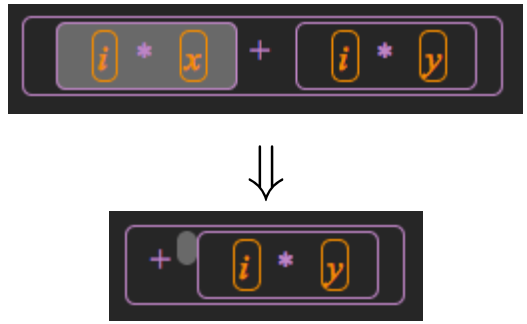
Insert edit

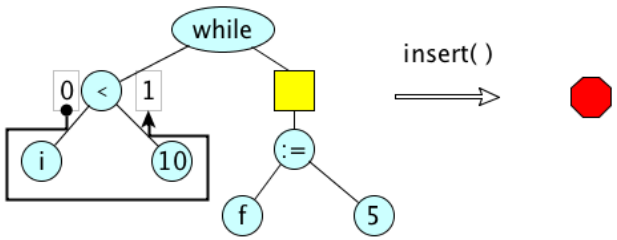
— replaces children with a new sequence

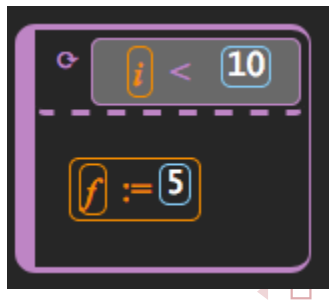








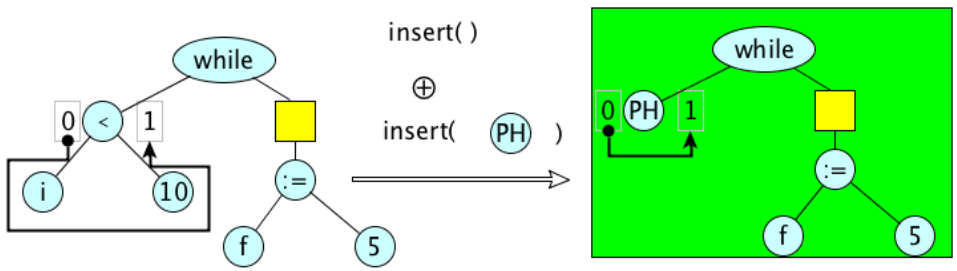


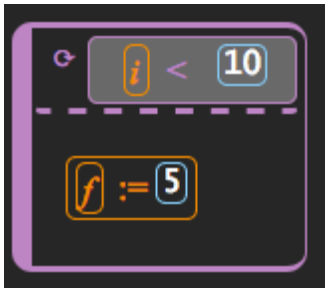


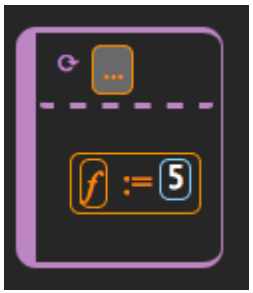
is unchanged.

A biased choice of edits

Implementing the delete key





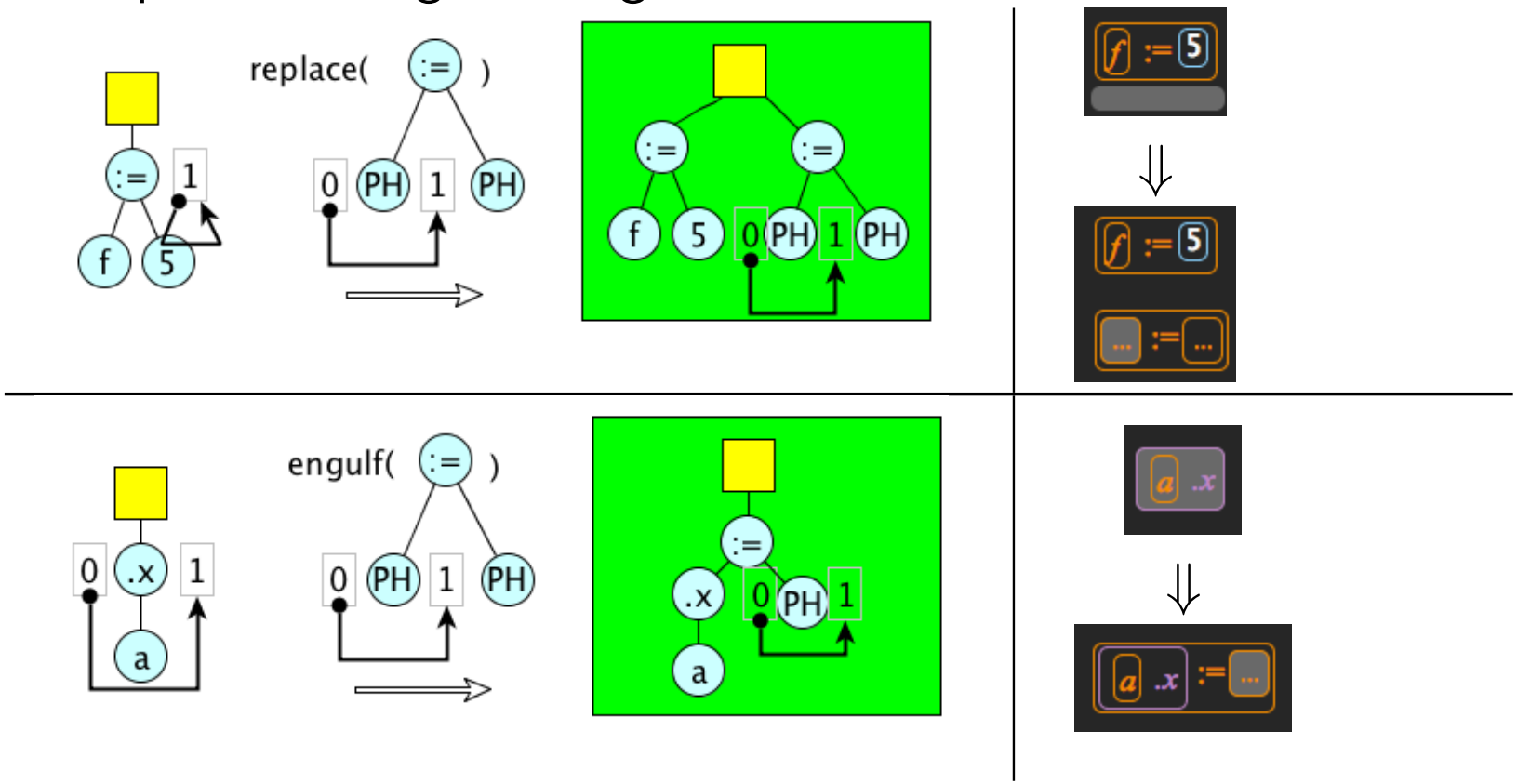


Biased choice allows context dependence.

Templates

Templates are selections. We use them to make edits.

Example: Inserting an assignment.



Many keys are bound to $\texttt{replaceOrEngulf}(t) = (\texttt{allPH} \circ \texttt{replace}(t)) \oplus \texttt{engulf}(t) \oplus \texttt{replace}(t)$ for some t.

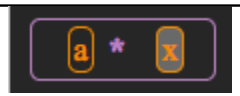
Making an efficient UI

Prefix entry of an expression

Keystrokes	Edits	Display
+	replace	
*	replace	
a	replace	
tab	change label, tab	
x	replace	
tab	change label, tab	
tab	tab	
* b tab y tab		

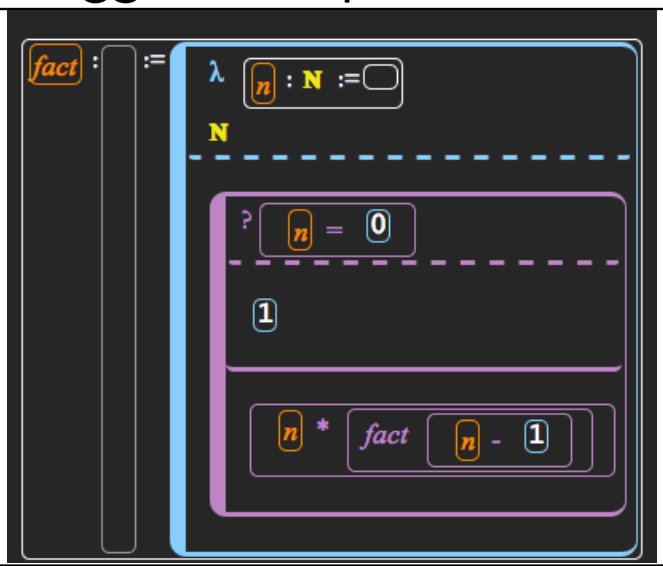
Making an efficient UI

Infix entry of an expression

Keystrokes	Edits	Display
a	replace	
enter	change-label	
*	engulf	
x	replace	
enter	change-label	
space	out	
+	engulf	
b, enter, *, y, tab		

Making an efficient UI

Both examples take 11 keystrokes.
The equivalent in C is at least 7: a*x+b*y
In general equivalent programs are roughly the same number of keystrokes.
A bigger example:




```
int fact(int n){
    return n==0 ? 1 : n*fact(n-1);
}
```

44 keystrokes	52 keystrokes

Reflection on the Software Engineering

Sometimes small decisions make significant differences.
In this project, we made several key small decisions:

- Checked constructors ensure invariants are established.
- Use immutable structures to ensure invariants are not broken.
- Validity is declarative and is checked by subclasses of `PLabel` that are application specific.
- Edits are not responsible for checking validity. This makes them largely application generic.
- Options mean that most errors are caught by the type checker. No "Oops, I forgot to check that ...".
- Complex edits are composed from simpler ones.

Reflection on the user experience engineering.

Sometimes small decisions make significant differences.
In this project, we made several key small decisions:

- Only allow valid trees.
- One UI action can mean several things.
  - We can pick the first edit to succeed.
  - Or we can leave the choice to the user.
- Make the current selection easy to choose and manipulate.
- Prefer easy of use to logical simplicity

Thanks to students who have worked with me on PLAAY

- Lawrence Bouzane
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