Why Separation Logic is the Bee's Knees, and why you should care

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8th December 2005 (version 3.0)

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- Advances in computing are advances in formalism, and vice-versa.

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```
var   reading, latest : bit
      slot : array bit of bit
      data : array bit of array bit of datatype

procedure   write    (item : datatype);
            var      pair, index : bit;
            begin
                     pair := not(reading);
                     index := not(slot[pair]);
                     data[pair, index] := item;
                     slot[pair] := index;
                     latest := pair
            end;

procedure   read :   datatype;
            var      pair, index : bit;
            begin
                     pair := latest;
                     reading := pair;
                     index := slot[pair];
                     read := data[pair, index]
            end;
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- (Concurrent programming programs are small: it's no coincidence.)

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- Milner's CCS and Hoare's CSP were attempts to re-engineer concurrency in terms of message passing and identifiable processes.
- They were both impossible to use. They both rumble on in PhD theses, and will do so for ever.

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- Steve Brookes has said sorry for failure semantics, and pointed out that if you use asynchronous message-passing and sort-of-infinite buffers, it all gets easier still. And I now know how to fix Pascal-m.

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- Structured Programming was a Bloody Good Idea, in stark contrast to Software Engineering (UML, anybody?).

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- Types won when they reached C, because they helped people to program more safely with C pointers and procedure calls (though C syntax did its best to stop them).
- Bertrand Meyer (Eifell) thinks that OOP is based on the idea of types. Would that it were so! (The road to Hell is paved with good intentions.)

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- Pointers were *right out*, and probably anathema.

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- That train wreck haunts us still: half of you are here to laugh at my idiocy in still trying to ride the rails.

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- Here we are around our campfire, telling stories and wondering if the smoke will have gone before the dawn. You’re all pretty demoralised.

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- This time, the hoo-hah is going to work for real.

How to implement a binary tree

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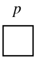

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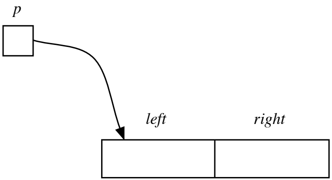

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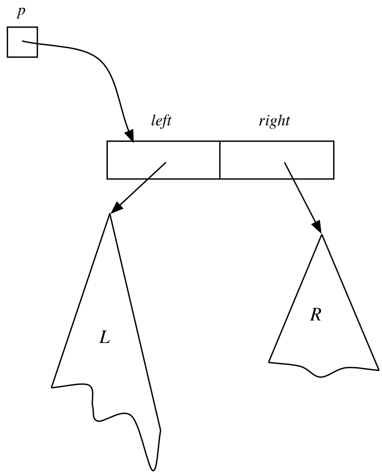

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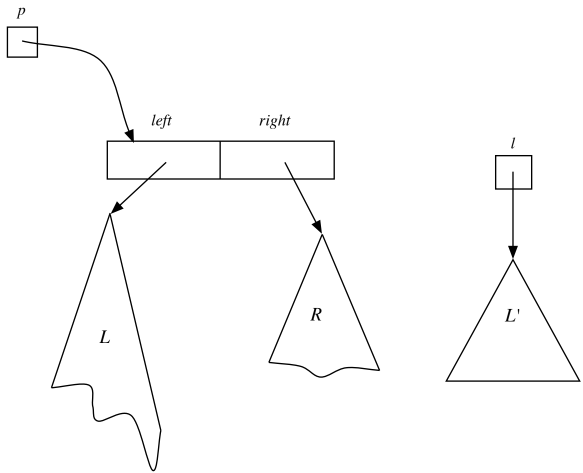
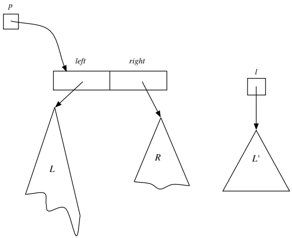


... and an alternative left subtree.

How to replace L with L'?



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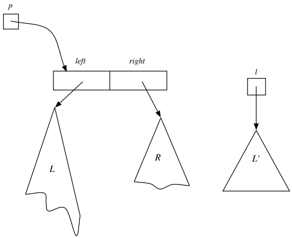

What could be easier?

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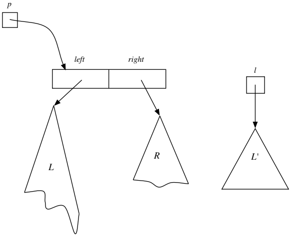

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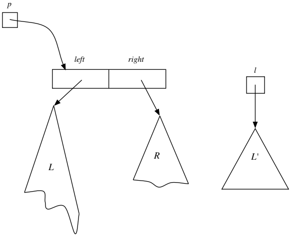
$$temp := p.left;$$
$$p.left := l;$$
$$\text{disposetree } temp$$

How to replace L with L'?



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(basic first-year undergrad stuff!)

How to describe a tree (Reynolds)

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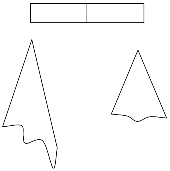
Trees come apart, into three separate sections.



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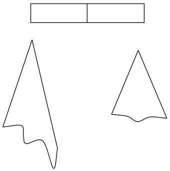

$$
\begin{aligned}
\mathsf{tree}\,\mathsf{Empty}\;p &\;\hat{=}\; p = \mathrm{nil} \wedge \mathbf{emp} \\
\mathsf{tree}\,\mathsf{Node}(\lambda, \rho)\;p &\;\hat{=}\; \exists l, r \cdot (p \mapsto l, r \star \mathrm{tree}\;\lambda\;l \star \mathrm{tree}\;\rho\;r)
\end{aligned}
$$

($p \mapsto l, r$ is a record, $A \star B$ is heap separation)

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- $E \mapsto F_0, F_1$ is just shorthand for $E \mapsto F_0 \star E + 1 \mapsto F_1$.

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- The ‘small axioms’ of assignment are

$$
\begin{array}{ll}
\{\mathbf{emp}\}\, x := \mathrm{new}()\, \{x \mapsto \_\} & \\
\{E \mapsto \_\}\ \mathrm{dispose}\, E\, \{\mathbf{emp}\} & \\
\{R[E/x]\}\, x := E\, \{R\} & (\text{the Hoare axiom}) \\
\{E \mapsto F\}\, x := [E]\, \{x = F \wedge E \mapsto F\} & (x \text{ not free in } E, F) \\
\{E \mapsto \_\}\ [E] := F\, \{E \mapsto F\} &
\end{array}
$$

Three inference rules

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$$\frac{\{Q_1\}\, C_1\, \{R_1\} \quad \{Q_2\}\, C_2\, \{R_2\} \quad \ldots \quad \{Q_n\}\, C_n\, \{R_n\}}{\{Q_1 \star Q_2 \star \cdots \star Q_n\}\, C_1 \mid\mid C_2 \mid\mid \cdots \mid\mid C_n\, \{R_1 \star R_2 \star \cdots \star R_n\}}$$

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- The CCR rule (has *atrocious* side condition):

$$\frac{\{(Q \star I_b) \wedge G\}\ C\ \{R \star I_b\}}{\{Q\}\ \text{with } b \text{ when } G \text{ do } C \text{ od}\ \{R\}}$$

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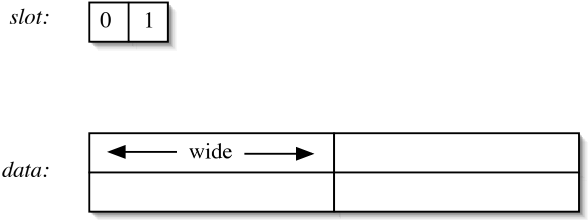
- Permissions (fractions of $\mapsto$, counts of $\rightarrowtail$) to allow sharing of heap;
- Variable permissions, to allow variables to be resource;
- Trivial side conditions;
- No side conditions at all (very new, this!).

Data structures: a bit array and a wide data array



Nine lines are now ten, with added auxiliary proof-variables

write: with $bundle$ when true do $pair :=$ not$(reading)$; $wuse := pair$ od;
$index :=$ not$(slot[pair])$;
$data[pair, index] := item$;
with $bundle$ when true do $slot[pair] := index$; $wuse := -1$ od;
with $bundle$ when true do $latest := pair$ od

read: with $bundle$ when true do $pair := latest$ od;
with $bundle$ when true do $reading := pair$ od;
with $bundle$ when true do $index := slot[pair]$; $ruse := index$ od;
$read := data[pair, index]$;
with $bundle$ when true do $ruse := -1$ od

What the writer owns

(A point of notation: I've used a special form of $\mapsto$ to describe a heap, just to make the slides easy to read.

For example, $data[pair, index] \mapsto \_$ replaces $data + 2 \star pair + index \mapsto \_$.

There is no change in meaning.)

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There is no change in meaning.)

$$latest_{0.5}, slot_{0.5}, data_{0.33}, wuse_{0.5}, pair, index$$

$$\models \left(\begin{array}{l} slot[0] \underset{0.5}{\longmapsto} \_ \star slot[1] \underset{0.5}{\longmapsto} \_ \star \\ \text{if } wuse \geq 0 \text{ then } data[pair, index] \mapsto \_ \text{ else } \mathbf{emp} \text{ fi} \end{array} \right)$$

What the reader owns

$$reading_{0.5}, ruse_{0.5}, data_{0.33}, pair, index$$
$$\models \text{if } ruse \geq 0 \text{ then } data[pair, index] \mapsto \_ \text{ else } \mathbf{emp} \text{ fi}$$

The bundle owns the rest

$$latest_{0.5}, reading_{0.5}, slot_{0.5}, data_{0.33}, wuse_{0.5}, ruse_{0.5}$$

$$\models \exists s \cdot \left(\begin{array}{l} slot[0] \underset{0.5}{\longmapsto} s(0) \star slot[1] \underset{0.5}{\longmapsto} s(1) \star \\ \text{if } wuse \geq 0 \wedge ruse \geq 0 \text{ then} \\ \quad data[reading, \text{not}(ruse)] \mapsto \_ \star data[wuse, s(wuse)] \mapsto \_ \\ \text{elsf } wuse \geq 0 \text{ then} \\ \quad data[wuse, s(wuse)] \mapsto \_ \star \\ \quad data[\text{not}(wuse), s(\text{not}(wuse))] \mapsto \_ \star data[\text{not}(wuse), \text{not}(s(\text{not}(wuse)))] \mapsto \_ \\ \text{elsf } ruse \geq 0 \text{ then} \\ \quad data[reading, \text{not}(ruse)] \mapsto \_ \star \\ \quad data[\text{not}(reading), s(\text{not}(reading))] \mapsto \_ \star data[\text{not}(reading), \text{not}(s(\text{not}(reading)))] \mapsto \_) \\ \text{else} \\ \quad data \mapsto \_, \_, \_, \_ \\ \text{fi} \end{array} \right)$$

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$$\left\{\; latest_{0.5}, slot_{0.5}, data_{0.33}, wuse_{0.5}, pair, index \vDash wuse = -1 \wedge slot[0] \underset{0.5}{\longmapsto} \_ \star slot[1] \underset{0.5}{\longmapsto} \_ \;\right\}$$

with $bundle$ when true do $pair :=$ not$(reading)$; $wuse := pair$ od;

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with *bundle* when true do

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pair := not(*reading*);

$$\left\{ \begin{array}{l} \mathit{latest}, \mathit{reading}_{0.5}, \mathit{slot}, \mathit{data}_{0.66}, \mathit{wuse}, \mathit{pair}, \mathit{index} \\ \models \exists s \cdot \left(\begin{array}{l} \mathit{wuse} = -1 \wedge \mathit{pair} = \mathrm{not}(\mathit{reading}) \wedge \mathit{slot} \mapsto s(0), s(1) \star \\ \mathit{data}[\mathrm{not}(\mathit{reading}), s(\mathrm{not}(\mathit{reading}))] \mapsto \_ \star \mathit{data}[\mathrm{not}(\mathit{reading}), \mathrm{not}(s(\mathrm{not}(\mathit{reading})))] \mapsto \_ \star \\ \text{if } \mathit{ruse} \geq 0 \text{ then } \mathit{data}[\mathit{reading}, \mathrm{not}(\mathit{ruse})] \mapsto \_ \\ \qquad\qquad \text{else } \mathit{data}[\mathit{reading}, s(\mathit{reading})] \mapsto \_ \star \mathit{data}[\mathit{reading}, \mathrm{not}(s(\mathit{reading}))] \mapsto \_ \\ \text{fi} \end{array} \right) \end{array} \right\}$$

wuse := *pair*

$$\left\{ \begin{array}{l} \mathit{latest}, \mathit{reading}_{0.5}, \mathit{slot}, \mathit{data}_{0.66}, \mathit{wuse}, \mathit{pair}, \mathit{index} \\ \models \exists s \cdot \left(\begin{array}{l} \mathit{wuse} = \mathit{pair} \wedge \mathit{pair} = \mathrm{not}(\mathit{reading}) \wedge \mathit{slot} \mapsto s(0), s(1) \star \\ \mathit{data}[\mathrm{not}(\mathit{reading}), s(\mathrm{not}(\mathit{reading}))] \mapsto \_ \star \mathit{data}[\mathrm{not}(\mathit{reading}), \mathrm{not}(s(\mathrm{not}(\mathit{reading})))] \mapsto \_ \star \\ \text{if } \mathit{ruse} \geq 0 \text{ then } \mathit{data}[\mathit{reading}, \mathrm{not}(\mathit{ruse})] \mapsto \_ \\ \qquad\qquad \text{else } \mathit{data}[\mathit{reading}, s(\mathit{reading})] \mapsto \_ \star \mathit{data}[\mathit{reading}, \mathrm{not}(s(\mathit{reading}))] \mapsto \_ \\ \text{fi} \end{array} \right) \end{array} \right\}$$

od;

$$\left\{ \begin{array}{l} \mathit{latest}_{0.5}, \mathit{slot}_{0.5}, \mathit{data}_{0.33}, \mathit{wuse}_{0.5}, \mathit{pair}, \mathit{index} \\ \models \mathit{wuse} = \mathit{pair} \wedge \exists i \cdot \left(\mathit{slot}[\mathit{pair}] \underset{0.5}{\longmapsto} i \star \mathit{slot}[\mathrm{not}(\mathit{pair})] \underset{0.5}{\longmapsto} \_ \star \mathit{data}[\mathit{pair}, \mathrm{not}(i)] \mapsto \_ \right) \end{array} \right\}$$

The reader is even easier than the writer!

$\{\ reading_{0.5}, ruse_{0.5}, data_{0.33}, pair, index \vDash ruse = -1\ \}$

with *bundle* when true do *pair* := *latest* od;

with *bundle* when true do *reading* := *pair* od;

with *bundle* when true do *index* := *slot*[*pair*]; *ruse* := *index* od;

$read := data[pair, index];$

with *bundle* when true do *ruse* := -1 od

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with *bundle* when true do $index := slot[pair]$; $ruse := index$ od;

$read := data[pair, index]$;

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with $bundle$ when true do $index := slot[pair]; ruse := index$ od;
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$read := data[pair, index]$;

$$\left\{ \begin{array}{l} reading_{0.5}, ruse_{0.5}, data_{0.33}, pair, index \\ \quad \vDash ruse \geq 0 \wedge reading = pair \wedge \exists i \cdot data[pair, index] \mapsto i \wedge read = i \end{array} \right\}$$

with $bundle$ when true do $ruse := -1$ od

$\{\; reading_{0.5}, ruse_{0.5}, data_{0.33}, pair, index \vDash ruse = -1 \;\}$

The rest of the reader is too easy to bother with

$$\text{with } bundle \text{ when true do } index := slot[pair]; \color{green}{ruse} := index$$

(in the reader) is very very *very* similar to

$$\text{with } bundle \text{ when true do } pair := \mathsf{not}(reading); \color{green}{wuse} := pair \text{ od}$$

(which I just showed you in detail from the writer),

so you don’t need to see it.

The rest of the reader is too easy to bother with

with $bundle$ when true do $index := slot[pair];\ ruse := index$

(in the reader) is very very *very* similar to

with $bundle$ when true do $pair := \mathrm{not}(reading);\ wuse := pair$ od

(which I just showed you in detail from the writer),

so you don't need to see it.

And the rest of the reader is trivial.

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- For the *very first time* we have nice proofs of a nine-line algorithm.
- I hope it has been worth the wait.

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- Matthew Parkinson, then Matthew Parkinson and I, did proofs of some old concurrency puzzlers.