Provenance-Awareness in R

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Outline

1 A Brief History of R

2 Provenance-Aware R

3 Issues

4 Conclusion

What is R?

- A language and interactive environment for statistical computing and graphics
  - **Language**: Lazy Functional; Strongly-typed; C-like syntax
  - **Environment**: Read *expressions* from a prompt and evaluates them; package based for extensibility
  - Snippet of R code:

```
> x <- 1:5
> y <- x * 2
> y
[1] 2 4 6 8 10
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- Is used extensively in many industries, and enjoys an extremely active userbase
- Most interestingly: R is an open-source implementation of S

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Early Provenance-Aware Computing: New S

In 1988 *New-S* succeeded *S*, and it became one of – if not – the first provenance-aware software applications with its novel **S AUDIT** facility. Its authors, Becker and Chambers describe it in their paper *Auditing of Data Analyses*[1].

An **audit file** was maintained by *New-S* which recorded each top-level command issued in this and previous sessions within the workspace, and identified those objects read from and written to.

[1] SIAM J. Sci. Stat. Comput. 9 [1988] pp. 747–60

S AUDIT

Example S AUDIT File

```
#~New session: Time: 542034997; Version: "S Tue Mar 3 10:14:20 EST 1987"
m<-matrix(read("brain.body"),byrow=T,ncol=2)
#~put "/usr/rab/.Data/m" 542035057 "structure"
brain<-m[,1]
#~get "/usr/rab/.Data/m" 542035057 "any"
#~put "/usr/rab/.Data/body" 542035072 "real"
plot(body,brain)
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What is recorded in the S AUDIT file:

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- Data objects read
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Environments and Bindings

R is dynamically typed. This is handled by Bindings.
During the evaluation of:

```
x <- 5
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- *x* is a symbol
- *5* is a vector (of one element)
- A binding associates a value with a symbol
- This binding is stored in the global environment

There are multiple environments; each containing their own bindings.
Environments may also enclose other environments.

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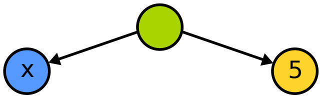

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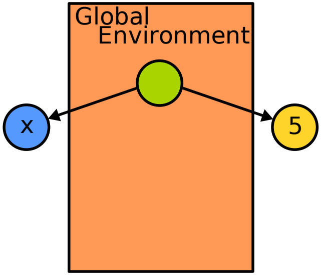

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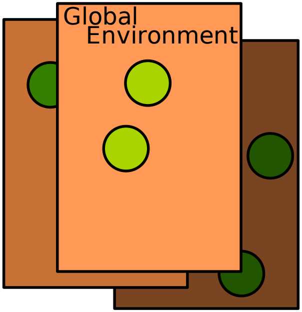

What Provenance?

- Bindings connect Symbols with Values
- So when talking about Provenance of data items, we need to know about Bindings, rather than then Value objects.

The principal objectives of a Provenance-Aware R are to identify the following of a given binding:

- Pedigree: The full sequence of commands responsible
- Parents: Bindings that have been read during its creation
- Children: Bindings that have read it during their creation

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Strategy

What we need to go about this:

- A mechanism for trapping reads and writes in the user workspace (i.e. the global environment)
- Containers for storing provenance information
  - Associated with bindings
- New R commands for inspecting provenance
  - provenance(x): Returns a list comprising: expression, symbol, timestamp, parents, children
  - pedigree(x): Displays the sequence of commands that has led to binding x's current state

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Making it Easier: The CXXR Project

Rather than working with the original C version of R, we have introduced provenance-awareness to CXXR.

Founded in 2007, CXXR[2] aims to progressively reengineer the R interpreter from C into C++, with the intention that Full functionality of the standard R distribution is preserved and so that behaviour of R code is unaffected.

CXXR allows Monitor functions to be set on bindings, which are triggered when a read or write occurs (in a given environment).

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Architecture of PA-CXXR

For each top-level expression:

- Maintain:
  - Seen set : Bindings read, or written
  - Parentage list : Bindings read (in order)
- On read of binding *x*:
  - If *x* is not in Seen:
    Add references to *x*'s Binding to Parentage and Seen
- On write of Binding *x*:
  - Create a Provenance object, which:
    - References the top level expression being evaluated
    - References the symbol with which it is associated
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  - Register *x* as a child of each of its parents
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Loops

Iterative loops cause bindings to be read from and written to multiple times.

It is not necessary to record this information in order to establish accurate parentage (and offspring); however, it may be useful to do so (e.g. How many loop iterations were there?).

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Lazy Evaluation

At the heart of R's lazy evaluation mechanism is a Promise object comprising:

- An Expression that is to be evaluated
- An Environment in which to evaluate it

Promises present a slight challenge

- Not evaluated until necessary
- Evaluation may result in creation of a new binding
- Originally, this new binding was excluded from the parentage because of the Seen set mechanism
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R has a function `source(filepath)`. The file given as an argument is opened, parsed, and each line is turned into an expression that is then evaluated. This is occurs outside of R's usual **R**ead-**E**valuate-**P**rint **L**oop (REPL).

Two options for handling this:

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- **White box:**

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  - Created bindings recorded as resulting from the precise expression evaluated
  - Appears as though the expressions were simply evaluated at the command line
  - No record of the exact call to `source` — although `source` function is recorded as a parent!

`source(...)`

R has a function `source(filepath)`. The file given as an argument is opened, parsed, and each line is turned into an expression that is then evaluated. This is occurs outside of R's usual **R**ead-**E**valuate-**P**rint **L**oop (REPL).

Two options for handling this:

- **Black box**:
  - Created bindings recorded as resulting only from the call to `source`
  - Cannot recall the precise expressions
  - Accurate in terms of the user's session
- **White box**:
  - Created bindings recorded as resulting from the precise expression evaluated
  - Appears as though the expressions were simply evaluated at the command line
  - No record of the exact call to `source` — although `source` function is recorded as a parent!

Conclusion and Future Work

We have demonstrated that it is possible to introduce provenance tracking facilities to a statistical environment, and as a result we can identify an artifact's pedigree, parents and children.
We now need to look into the following

- Reproducing data from provenance information
- Effectively handle pseudo-random number generation
  - To enable reproducibility of results
- Recording provenance in other R environments
- Serializing provenance information
  - Serialization formats
  - OPM-compatability

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