ALTREP and Other Things

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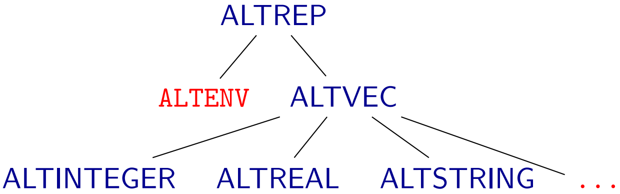
ALTREP: Alternate Representations for R Objects

- The C level R implementation works with a fixed set of data types, e.g. INTSXP, REALSXP, ENVSXP.
- Contents are accessed through a function/macro abstraction.
- ALTREP allows for alternate representations of these data types.
- To existing C code these look like ordinary R objects.
- Some of the goals:
  - allow vector data to be in a memory-mapped file or distributed;
  - allow compact representation of arithmetic sequences;
  - allow adding meta-data to objects;
  - allow computations/allocations to be deferred;
  - support alternative representations of environments.
- Current state is available in the ALTREP SVN branch.
- More details are available in ALTREP.md at the branch root.

Abstract Classes

- A set of abstract classes for R data types:



ALTREP

ALTENV ALTVEC

ALTINTEGER ALTREAL ALTSTRING ...

- The most specific classes correspond to R data types.
- Concrete classes specialize one of these.

Methods

General Methods

- ALTREP object methods:
    - Duplicate
    - Coerce
    - Length
    - Inspect
- The standard macros defer to these methods for ALTREP objects.
- Duplicate and Coerce methods can return NULL to fall back to the default behavior.

Methods
Vector Methods

- ALTVEC methods:
  - Dataptr
  - Dataptr_or_null
  - Extract_subset
- Dataptr may need to allocate memory; for now GC is suspended when calling the method.
- Dataptr_or_null will not allocate.
- Dataptr_or_null and Extract_subset can be used to avoid fully allocating an object

Methods

Specific Vector Methods

- Specific vector methods (patterned after JNI):
  - Elt
  - Set_elt
  - Get_region
  - No_NA
  - Is_sorted
  - and several others.
- Some numeric vector methods:
  - Min
  - Max
  - Sum
  - Prod

Changes to Existing Functions

- Some functions modified to avoid using DATAPTR:
  - mean
  - min
  - max
  - sum
  - prod.
- These use Get_region to process data in chunks.
- Many more functions could be modified along these lines.
- Subsetting has also been modified to avoid using DATAPTR.
- This means head, sample, for example, may avoid allocation.

Serialization and Package Support

- Classes can provide custom serialization by defining methods for
    - Serialized_state
    - Unserialize
- Packages can register ALTREP classes.
- Serialization records the package and class name.
- Unserializing loads the package namespace and looks up the registered class.
- A sample package implementing a memory mapped vector object is available on GitHub.

Sample Class Implementations

Compact Integer Vectors

- Vectors created by n1:n2, seq_along or seq_len can be represented compactly.
- In R 3.3.x (or 3.4.0 with JIT disabled)

```
> system.time(for (i in 1:1e9) break)
   user  system elapsed
  0.258   1.141   1.400
> x <- 1:1e10
Error: cannot allocate vector of size 74.5 Gb
```

- In the ALTREP branch:

```
> system.time(for (i in 1:1e9) break)
   user  system elapsed
      0       0       0
> x <- 1:1e10
> length(x)
[1] 1e+10
```

Sample Class Implementations

Deferred String Conversions

- Converting integers or reals to strings is expensive.
- In lm and glm default row labels on design matrices are created but rarely used.
- The ALTREP branch
  - modifies the internal coerce function to return a deferred string conversion object;
  - this class has a subset method that returns another deferred conversion object.
- For lm or glm with $n = 10^7$ and $p = 2$ this produces a 5 to 10 fold speedup.
- Deferred evaluation could be useful in many other settings as well.

Sample Class Implementations

Memory Mapped Vectors

- The ALTREP branch includes sample classes for memory mapped integer and real vectors.
- The file can be opened for reading and writing or in read-only mode.
- When used by ALTREP-aware code these will not result in allocating memory for holding all the data.
- Using non-aware functions may result in attempts to allocate large objects.
- The class provides an option for signaling an error when the raw data pointer is requested.

Sample Class Implementations

Wrapper Objects

- Currently changing an attribute on a shared vector requires a copy of the vector data.
- Wrapper can hold the new attribute value and a reference to the original object to access its data.
- Wrapper objects can also be used to attach meta-data, such as
  - is the vector sorted;
  - are there no NA values.
- The sort function returns a wrapper that records that the vector is sorted.

Some Implementation Details

- ALTREP objects are allocated as CONS cells with an altrep header bit set.
- Standard macros, like LENGTH look at this bit to decide whether to dispatch.
- To allow efficient scalar identification there is also a scalar bit,
- With the ALTREP changes operations like DATAPTR, STRING_ELT, and SET_STRING_ELT now might cause allocation.
- Eventually code should be rewritten to allow for this.
- For now, GC is suspended in these allocations.

Some Issues and Notes

- Deferred evaluations/allocations are very useful, but:
  - allocation failures can be delayed and come at unexpected times;
  - operations may produce unexpected large allocations, e.g. log(1:1e10);
  - some situations can lead to repeated evaluations.
  - Memory mapping issues:
    - serialization failure when the file is not available;
    - some settings might need a conversion layer (e.g. a file of 8-bit integers).
  - Length and data address consistency; can these change during object lifetime?
- Deferred edits might be useful for improving complex assignment performance.

Changes Needed in R-devel

- ALTREP needs one or two new header bits.
- This requires a binary-incompatible header change.
- Because of alignment issues, adding 32 bits to the header does not increase object sizes on (most if not all) 64-bit platforms.
- This also allows room for a reasonable size reference count.
- This does seem like a good opportunity to also reserve 64 bits for the vector length fields (which does increase vector object sizes).
- There is now a mechanism in place (R_INTERNALS_UUID) that prevents loading packages with compiled code created by a binary-incompatible R.
- It would be good to make this change fairly soon; if there are other header adjustments needed these could happen now also.

Transition Stages for R-devel

- Rough order of steps:
  - Header changes.
  - Add support for basic framework, packages.
  - Modify some functions to take advantage of support.
  - Create ALTREP object within R-devel.
- Header change will be most disruptive; best to do it soon.
- Will need to check against CRAN, Bioconductor at each stage.

Other Things

- Reference counting:
  - more maintainable;
  - allow less duplicating;
  - may help improving complex assignment performance.
- Compilation:
  - reduce remaining interpreted/compiled differences;
  - pre-compile packages by default;
  - more optimization opportunities.
- Integer and logical sum:
  - Currently sum(x $>$ 0) can return NA for a long vector.
  - Allow sum(x) to return a double?