5. Storage

5.6. Run time type information

The challenge of deep clone

"Algorithm" for Deep Clone:

- Start from current value.
- Traverse the network of values accessible from it.
- Duplicate this network

How should we "traverse" the network?

Definition (Network Traversal: breadth- (or depth-) first search)

In Each Value we Visit:

- *Mark the value as "visited"*
- *Proceed to all values it references*

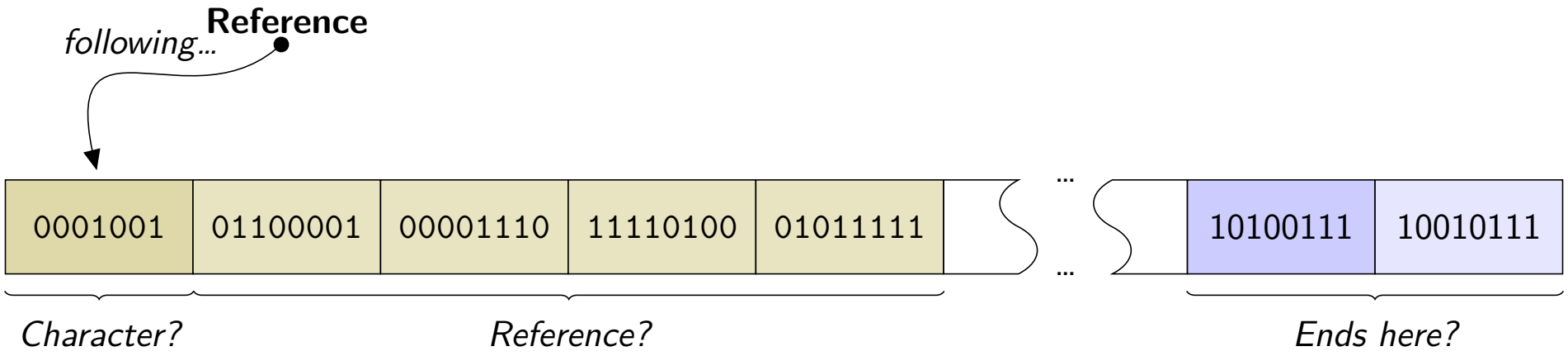
But, there is a catch...

Definition (Network Traversal: breadth- (or depth-) first search)

In Each Value we Visit:

- *Mark the value as "visited"*
- *Proceed to all values it references*

The challenge: When we reach a value, we do not what's in it!

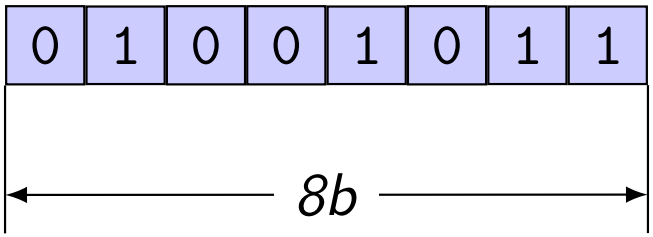


Memory = bits & bytes!

To understand the difficulty better, we need to take a second look at:

- Bits
- Bytes
- Values
- Types
- Memory representation of values
- The interpretation of memory representation

Example: different Interpretations of a single byte

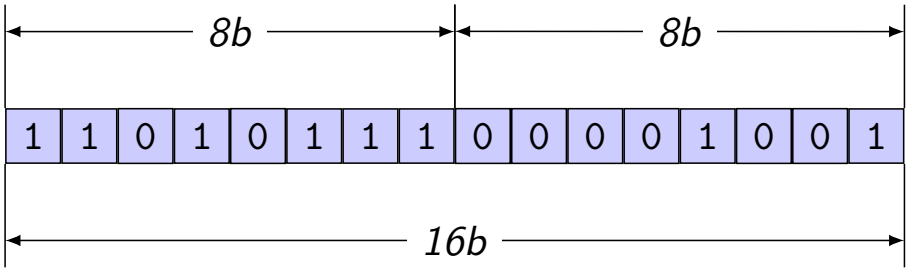



```
#include <stdlib.h>
#include <stdio.h>

main() {
  const void *p = malloc(1);
  *(unsigned char *)p = 0b1001011;
  printf("As␣integer:␣'%d';␣",*(char *)p);
  printf("as␣character:␣'%c'\n",*(char *)p);
}
```

```
As integer: '75'; as character: 'K'
```

Example: different interpretations of a 16 bits word



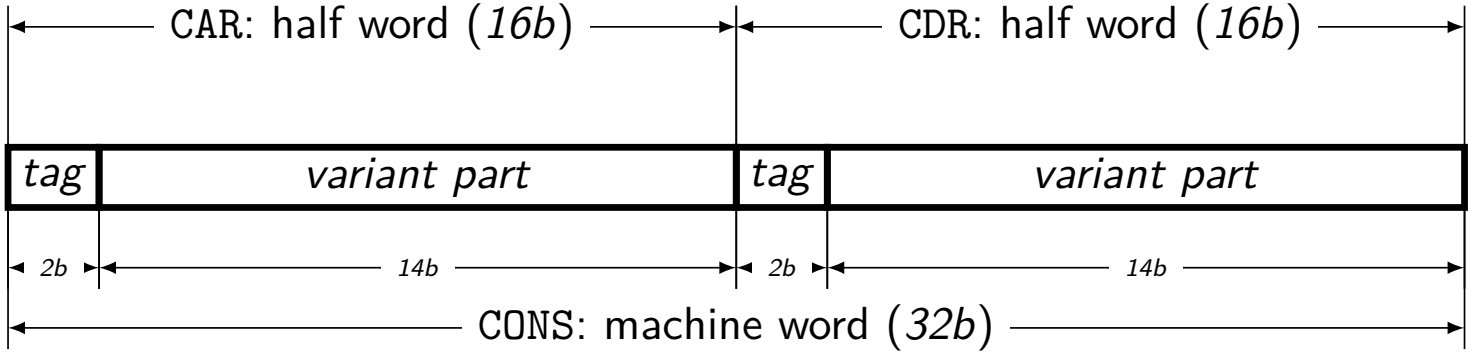

```
#include <stdlib.h>
#include <stdio.h>

main() {
  const void *p = malloc(2);
  *(unsigned short *)p = 0
     b1101011100001001;
  printf("As␣signed␣integer:␣'%d'\n
     ",
    *(signed short *)p);
  printf("As␣unsigned␣integer:␣'%d
     '\n",
    *(unsigned short *)p);
  printf("As␣an␣array:␣'(%d,%d)'\n"
     ,
    0[(char *)p],
    1[(char *)p]
  );
}
```

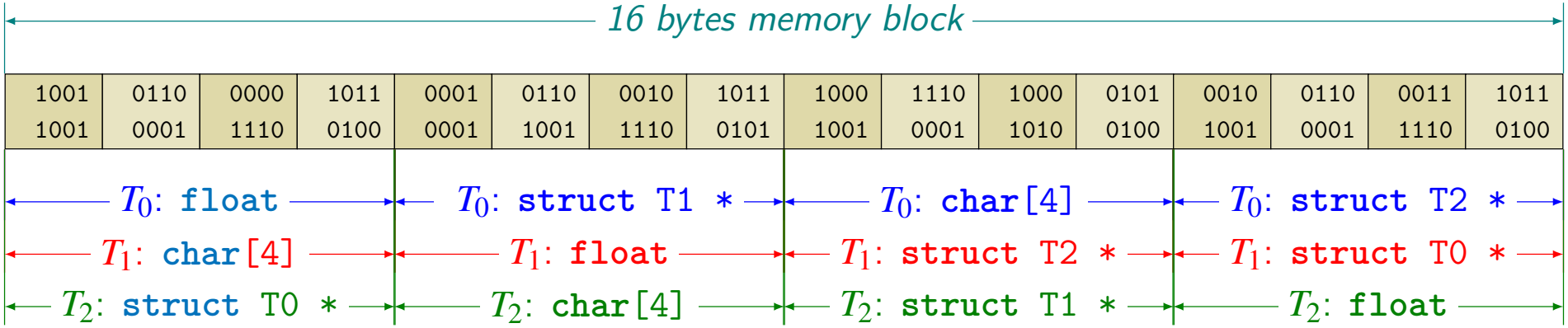
```
As signed integer: '-10487'
As unsigned integer: '55049'
As an array: '(9,-41)'
```

Example: different interpretations of 32 bits word

```
// A more civilized way to name integer values:
enum {
  // How many bits for index into pool:
  LG2_POOLSIZE = 14,
  // How many bits for storing car/cdr kind:
  KIND_SIZE = 2
};
enum kind { NIL, ATOM, STRING, INTEGER};
struct Cons {
   enum kind carKind: KIND_SIZE;
   unsigned int car: LG2_POOLSIZE;
   enum kind cdrKind: KIND_SIZE;
   unsigned int cdr: LG2_POOLSIZE;
};
```



The layout of a C structure



The same memory block could be interpreted in many different ways. Here is a 16 bytes block, which can be interpreted as **struct** T0, as **struct** T1, or, as **struct** T2.

```
struct T0 {
  float x;
  struct T1 *p;
  char s[4];
  struct T2 *q;
};
```

```
struct T1 {
  char s[4];
  float x;
  struct T2 *q;
  struct T0 *p;
};
```

```
struct T2 {
  struct T0 *p;
  char s[4];
  struct T1 *q;
  float x;
};
```

Summary: the "meaning" of bits and bytes

A value is represented in memory as a *sequence* of bits and bytes.

Components:

- Integers
- Floating point values
- Characters
- References
- Arrays
- Sets in bit mask representation.
- etc.

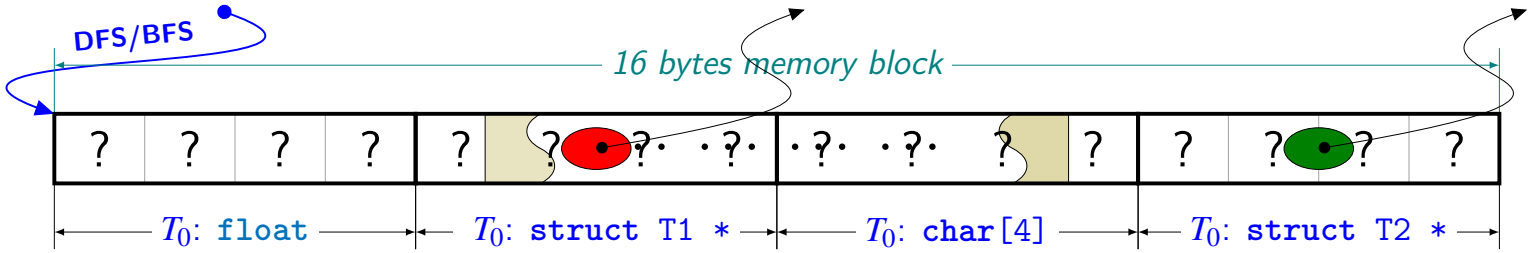
Deciphering a Value

- The values' type is the *key*
- It gives meaning to the bit representation.

Information provided by type:

- Value's length
- Partitioning into sections
- Appropriate way of interpreting each section

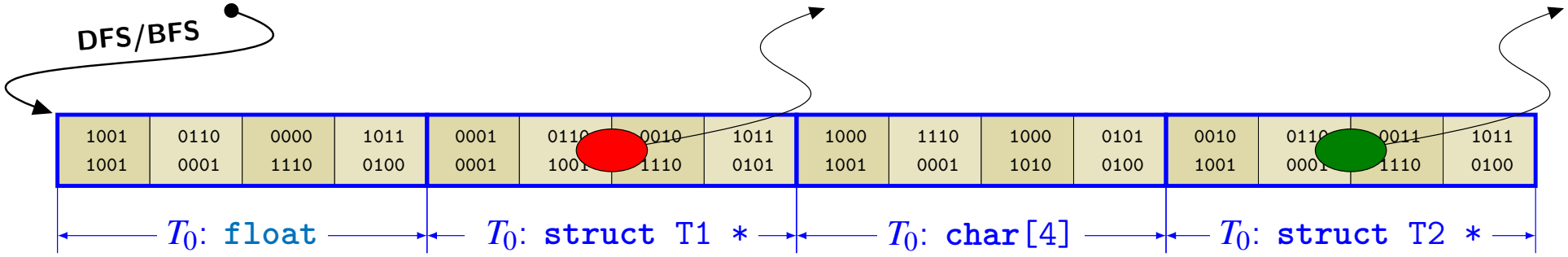
A step in a BFS/DFS tour



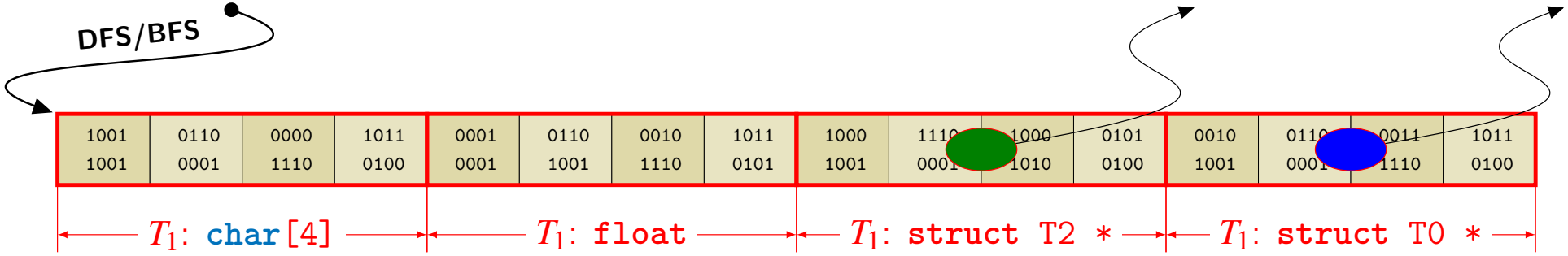

```
struct T0 { float x; struct T1 *p; char s[4]; struct T2 *q; };
```

- Suppose we are the midst of a DFS (or BFS) traversal in the values' graph, and we follow a reference, reaching a memory block. Unfortunately, a-priory, we do not know how long the block is.
- Further, although we can examine the bits and bytes, we cannot know what their values mean!
- *Supposing* that we know that the value is of type T_0, then, we know how long the memory block is, and that it has four words, of four bytes each, as well as the exact type of each of these words.
- With this information, we can continue the traversal, along the first reference found in this memory block, and then, along the second such reference.

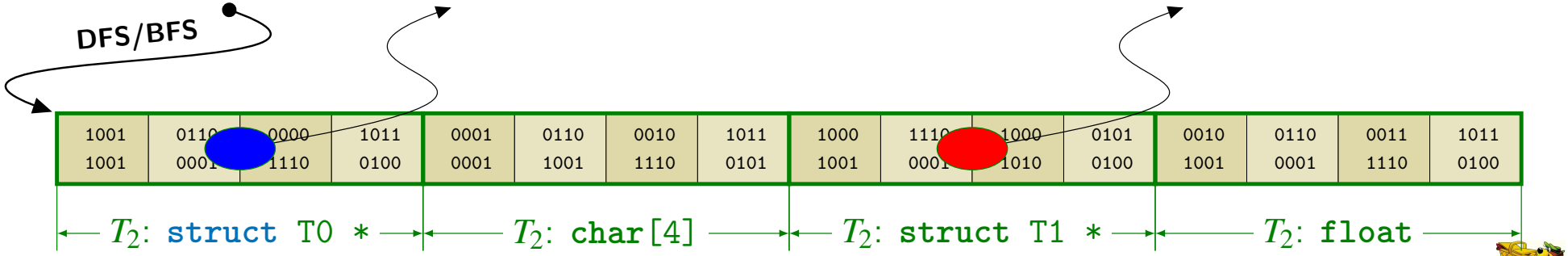
But, the visited block could be of any type!




```
struct T0 { float x; struct T1 *p; char s[4]; struct T2 *q; };
```




```
struct T1 { char s[4]; float x; struct T2 *q; struct T0 *p; };
```




```
struct T2 { struct T0 *p; char s[4]; struct T1 *q; float x;};
```

Interpreting bit and bytes as values of a type

Definition (Static typing)

The compiler knows the "deciphering key", and it generates code based on this information.

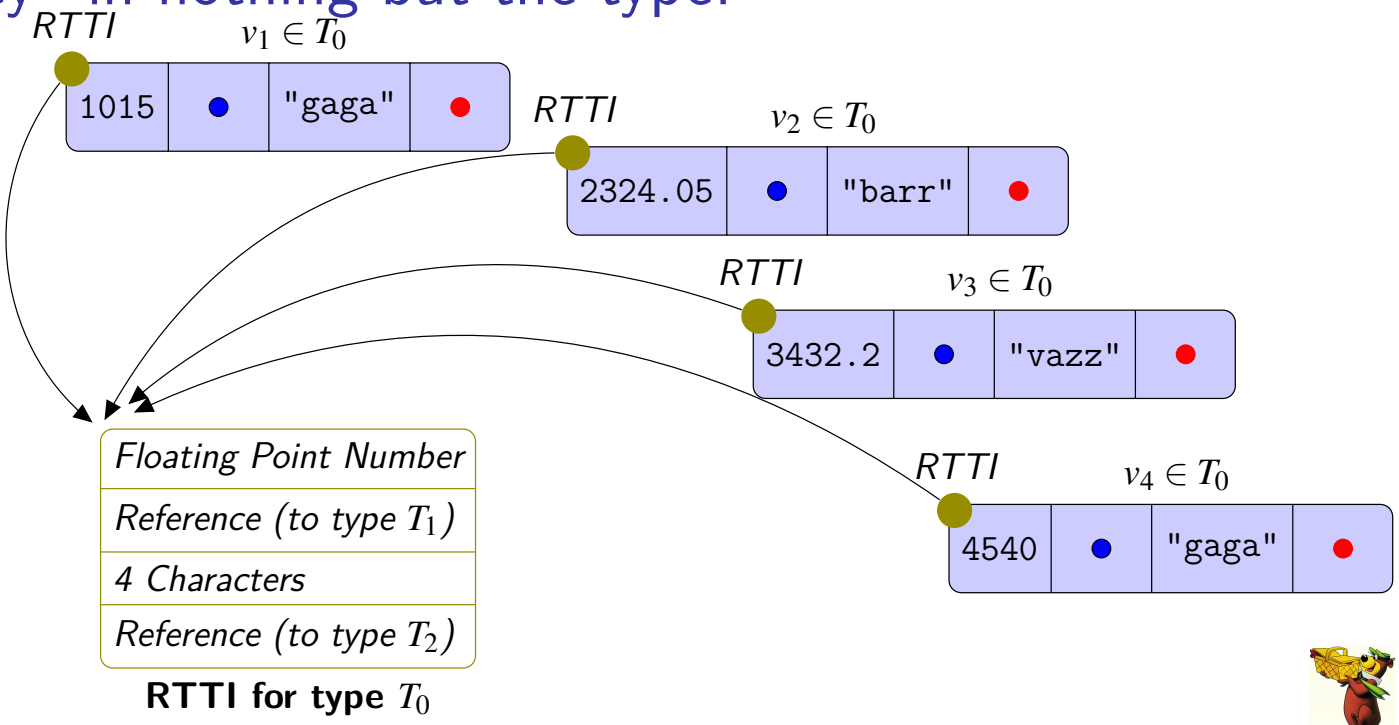
Definition (Dynamic typing)

A "deciphering key" is attached to each value; the run-time system decodes the key.

The "deciphering key" in nothing but the type!

RTTI field may contain all the type information

more commonly, *RTTI is a reference to a "type descriptor" shared by all values of the type.*



Designing an algorithm for traversing values

Can we use static type information?

No!!!

- The network of objects typically contains values of very many distinct types
- The traversal algorithm should know
  - the type of each visited value,
  - the types of each of the values it references
- It is impractical to generate a different traversal algorithm for each input program as per the the different that occur in it.

RTTI is the answer!

Definition (Run-time type information)

Run-time type information *(or RTTI for short) is a tag attached to each value, which specifies its type.*

Application of RTTI in different kinds of PLs:

Statically Typed

- Deep cloning,
- Garbage collection, *and*,
- Serialization.

Dynamically Typed

- Deep Cloning,
- Garbage Collection,
- Serialization, *and*,
- Run time type checks

C, C++, & RTTI

- As a result of the "*no hidden cost*" language principle, C does not and cannot have RTTI.
- As a result, C cannot have general purpose GC, serialization, cloning or any deep operations.
- Due to the "C-*compatibility at almost all costs*" language principle, C++ does not and cannot have RTTI.
- As a result, C++ cannot have general purpose GC, serialization, cloning or any deep operations.
- C++ has a limited form of RTTI for the implementation of `virtual` functions.
- More on these mysterious "*vptr*" and "*vtbl*" in our OOP course.

Use of RTTI in the implementation of different PLs

- Consider a variable `today` which references an object with (say) three fields: `year`, `month`, `year`
- How is `today.day=35` being implemented?

prog. lang.	C	JAVA	JAVASCRIPT
syntax	`today->day=35`	`today.day=35`	`today.day=35`
static typing	✓	✓	✗
dynamic typing	✗	✓	✓
RTTI	✗	✓	✓
type punning	✓	✗	✗
implementation	1. dereference `today` 2. advance by *off*(`day`) 3. update field	1. dereference `today` 2. ignore RTTI 3. advance by *off*(`day`) 4. update field	1. dereference `today` 2. examine RTTI 3. determine *off*(`day`) 4. advance by *off*(`day`) 5. update field

Comments on use of RTTI in PLs

- When and how is *off*(`day`), the function determining the field offset, determined?
- In statically typed languages:
  - at compile time
  - from the static type of `today`.
- In dynamically typed languages:
  - at runtime
  - from the RTTI of "`*today`"
- In C, the actual type of `*today` could be anything (due to type punning).
- In JAVA, the actual type of the object that `today` refers to, can be any class that `extends` class `Date`.