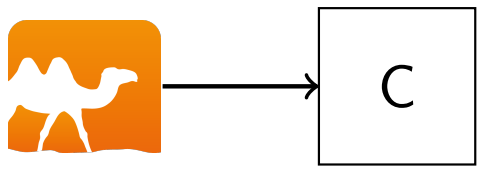
An application: foreign function bindings




```
int puts(const char *s);
```

C in two minutes

object types

numeric types

`int`, `char`, `float`, ...

pointers

`int *`, `char *`, `int **`, ...

structures and unions

```
struct t { int x, char y };
```

arrays

```
int x[3] = { 1, 2, 3};
```

Operations

address, sizeof, read, write, ...

function types

built from object types

n arguments, one return type

```
int(const char *);
char *(char *, char *);
```

Operations

call

Talking to C: two challenges

Conversions between value representations

`Long_val`, `Val_long`, `caml_copy_double`, ...

Interactions with the garbage collector

Protect locals & parameters against disappearance & destruction

```
value puts_stub(value s)
{
  CAMLparam1(s);
  const char *p = String_val(s);
  int n = puts(p);
  CAMLreturn(Val_int(n));
}
```

Representing types

Representing object types

C object types

```
type ::=
       int
       char
       type *
       ...
```

Representing C object types

```
type _ typ =
    Int : int typ
  | Char : char typ
  | Ptr : 'a typ → 'a ptr typ
  | ...
  | View : ('a → 'b)
         * ('b → 'a)
         * 'a typ → 'b typ
  | ...
```

```
let string : string typ =
  View (ptr_of_string, string_of_ptr, Ptr Char)
```

Operations on object types

Low-level operations

```
val read : 'a typ → address → 'a
val write : 'a typ → 'a → address → unit
val sizeof : 'a typ → int
```

```
let read : type a. a typ → address → a =
  fun typ addr → match typ with
    | Int → read_int address
    | Char → read_char address
    | ...
```

Higher-level operations

```
type 'a ptr (* = 'a typ * address *)
val (!@) : 'a ptr → 'a
val (@+) : 'a ptr → int → 'a ptr
```

Representing function types

C function types

```
ftype ::= type(type, type, ..., type)
```

Representing C function types

```
type _ fn = Returns : 'a typ → 'a fn
          | Function: 'a typ * 'b fn → ('a → 'b) fn

let (@→) a b = Function (a,b) and returning v = Returns v
```

Example

```
Ptr Char @→ Int @→ returning Int
```

represents

```
int(char *, int)
```

Operations on function types

```
val foreign : string → ('a → 'b) fn → ('a → 'b)
```

Example

```
let puts = foreign "puts" (string @→ returning int)
```

produces

```
val puts : string → int
```

Anatomy of a binding

```
let puts = foreign "puts" (string @→ returning int)
puts "Hello, world"
```

1. resolve the name
2. create a buffer with enough space
3. convert and write arguments
4. apply function
5. read results

Anatomy of a binding

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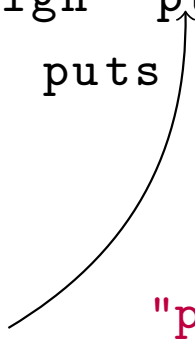

1. resolve the name `"puts"` ⇝ `0x7f0d1eebcf60`
2. create a buffer with enough space
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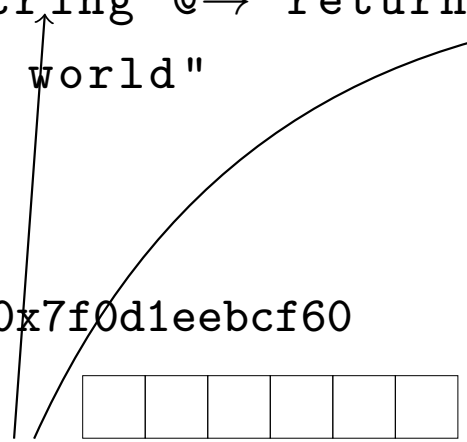

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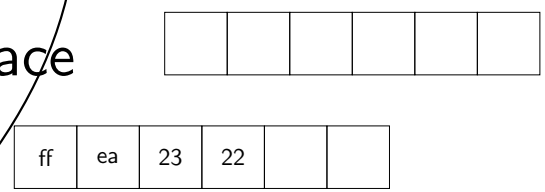

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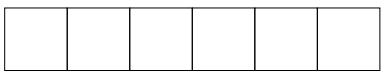
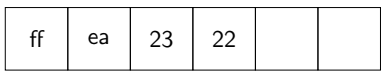
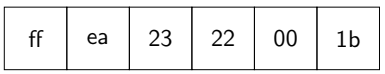
2. create a buffer with enough space 
3. convert and write arguments 

4. apply function 

5. read results

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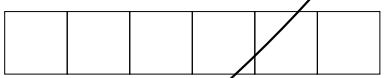
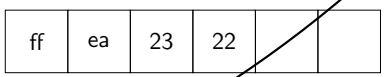
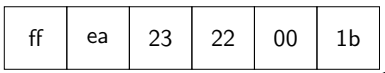
2. create a buffer with enough space 
3. convert and write arguments 

4. apply function 

5. read results ~~`puts`~~ `"Hello, world"` ⇝ `13`

More type interpretations

Drawbacks of dynamism

No **type safety**

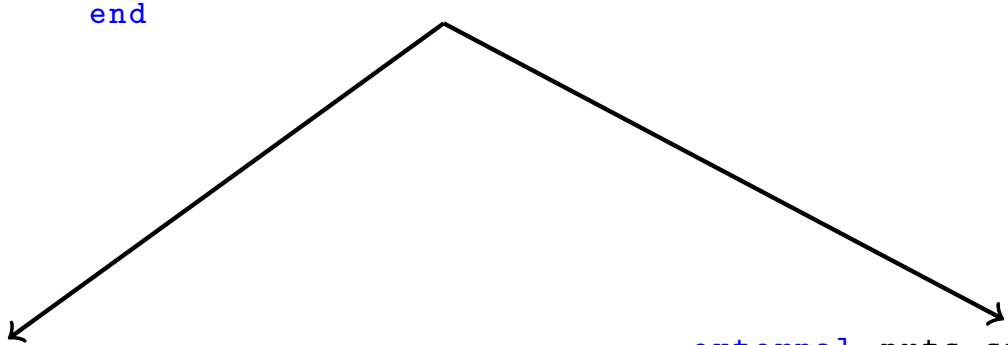
Name lookup may fail dynamically

Interpretive **overhead**

Can't use **standard tools** (`nm`, `objdump`, `ldd`, ...)

Staged binding

```
module Bindings(F: FOREIGN) = struct
 open F
 let puts = foreign "puts" (string @→ returning int)
end
```



```
value puts_stub(value s) {
 char *p = Ptr_val(s);
 int n = puts(p);
 return Val_int(n);
}
```

```
external puts_stub : address → int =
      "puts_stub"

let foreign nm fn = match nm, fn with
 | "puts", Function (View ...
```

```
Bindings(Generated_ML)
```

Staged binding

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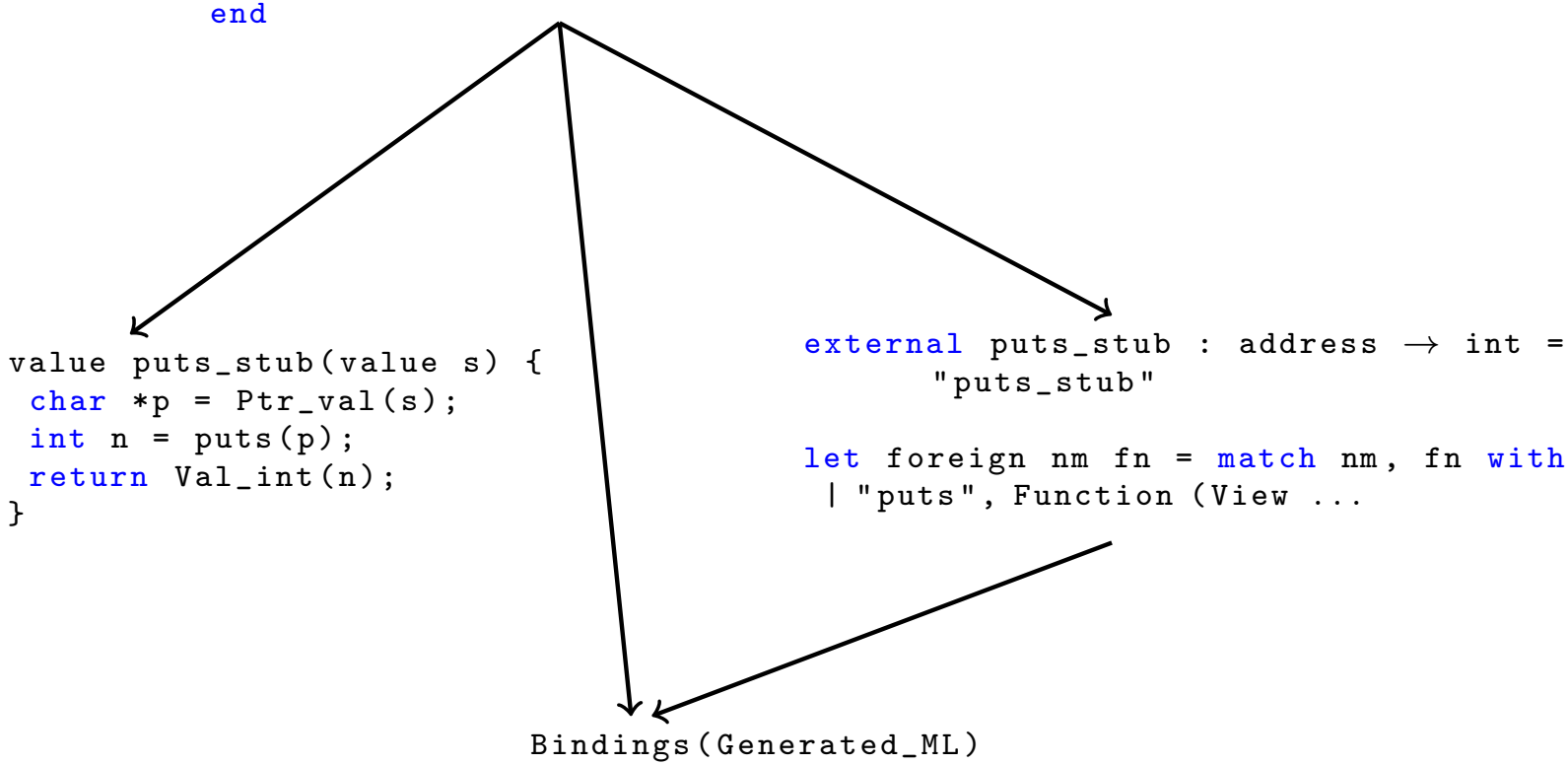

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external puts_stub : address → int =
      "puts_stub"

let foreign nm fn = match nm, fn with
 | "puts", Function (View ...
```

```
Bindings(Generated_ML)
```

Staged binding: abstracting the interpretation

```
module type FOREIGN = sig
 type _ result
 val foreign: string → ('a→'b) → ('a→'b) result
end
```

Example

```
module Bindings(F: FOREIGN) = struct
  open F
  let puts = foreign "puts" (string @→ returning int)
end
```

Staged binding: recovering the dynamic interpretation

```
module Foreign_dynamic = struct
 type 'a result = 'a
 let foreign = foreign (* i.e. implementation above *)
end
```

Example

`Bindings(Foreign_dynamic)`

produces

```
sig
 val puts : string → int
end
```

Staged binding: generating C

```
val generate_C : string → 'a fn → unit

module Foreign_generate_C = struct
 type 'a result = unit
 let foreign = generate_C
end
```

Example

```
Bindings(Foreign_generate_C)
```

outputs

```
value puts_stub(value s) {
 char *p = Ptr_val(s);
 int n = puts(p);
 return Val_int(n);
}
```

Staged binding: generating ML

```
val generate_ML : string → 'a fn → unit

module Foreign_generate_ML = struct
 type 'a result = unit
 let foreign = generate_ML
end
```

Example

```
Bindings(Foreign_generate_ML)
```

outputs

```
external puts_stub : address → int = "puts_stub"

let foreign nm fn = match nm, fn with
 | "puts", Function (View (_, froms, Ptr Char)) →
    fun s → puts_stub (froms s)
 | "puts", fn → fail "type mismatch"
 | name, _ → fail "unexpected name"
```

Staged binding: linking

```
module Bindings(F: FOREIGN) = struct
 open F
 let puts = foreign "puts" (string @→ returning int)
end
```

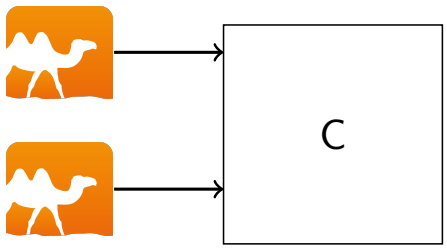
```
module Generated_ML : FOREIGN with type 'a result = 'a
  = (* code generated on previous slide *)
```

```
Bindings(Generated_ML)
```

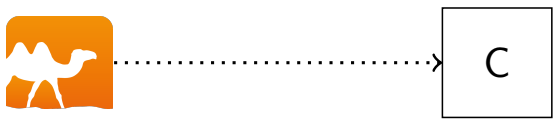
Type safe linking via type refinement!

(Some details omitted)

concurrency



remote calls



function pointers

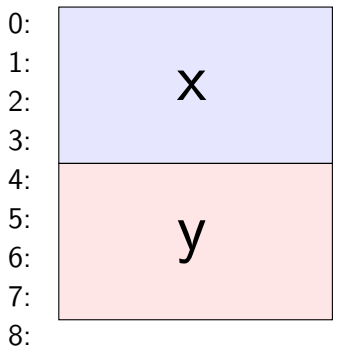
```
void (*)(int, float);
```

more object types

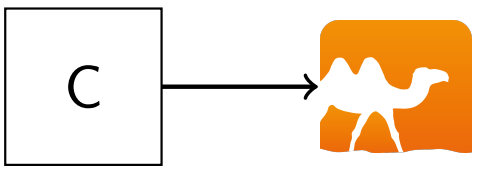
```
struct s x[3];
```

determining object layout

```
struct t {
  int x, y;
};
```



inverted bindings



Next time: overloading

```
val (=) : {E:EQ} → E.t → E.t → bool
```