So what does studying PL buy me?

Enables you to better choose the right language

“but isn’t that decided by

- libraries,
- standards,
- and my boss ?”

Yes. Chicken-and-egg.

My goal: educate tomorrow’s tech leaders & bosses
So you’ll make considered, informed choices

So what does studying PL buy me?

Makes you look at things in different ways, think outside of the box

Knowing language paradigms other than traditional ones will give you new tools to approach problems, even if you are programming in Java

PL Dimensions

- Wide variety of programming languages
- How do they differ?
- along certain dimensions...
- What are these dimensions?

Dimension: Syntax

- Languages have different syntax
  - But the difference in syntax can be superficial
  - C# and Java have different syntax, but are very similar
- In this class, will look beyond superficial syntax to understand the underlying principles

Dimension: Computation model

- Functional: Lisp, OCaml, ML
- Imperative: Fortran, Pascal, C
- Object oriented: Smalltalk, C++, Java, C#
- Constraint-based: Prolog, CLP(R)

Dimension: Memory model

- Explicit allocation-deallocation: C, C++
- Garbage collection: Smalltalk, Java, C#
- Regions: safe versions of C (e.g. Cyclone)
  - allocate in a region, deallocate entire region at once
  - more efficient than GC, but no dangling ptrs

Dimension: Typing model

- Statically typed: Java, C, C++, C#
- Dynamically typed: Lisp, Scheme, Perl, Smalltalk
- Strongly typed (Java) vs. weakly typed (C, C++)

Dimension: Execution model

- Compiled: C, C++
- Interpreted: Perl, shell scripting PLs
- Hybrid: Java

- Is this really a property of the language? Or the language implementation?
- Depends...

So many dimensions

- Yikes, there are so many dimensions!
- How to study all this!

- One option: study each dimension in turn

- In this course: explore the various dimensions by looking at a handful of PLs

Weekly Programming Assignments

Unfamiliar languages

+ Unfamiliar environments

Start Early!

Weekly Programming Assignments

Forget Java, C, C++ …

… other 20th century PLs

Don't complain

… that Ocaml is hard

… that Ocaml is @!#@%

Immerse yourself in new language

Free your mind.

Enough with the small talk

?

Say hello to OCaml

```
void sort(int arr[], int beg, int end){
  if (end > beg + 1){
    int piv = arr[beg];
    int l = beg + 1;
    int r = end;
    while (l != r-1){
       if(arr[l] <= piv)
          l++;
       else
          swap(&arr[l], &arr[r--]);
    }
    if(arr[l]<=piv && arr[r]<=piv)
       l=r+1;
    else if(arr[l]<=piv && arr[r]>piv)
       {l++; r--;}
    else if (arr[l]>piv && arr[r]<=piv)
       swap(&arr[l++], &arr[r--]);
    else
       r=l-1;
    swap(&arr[r--], &arr[beg]);
    sort(arr, beg, r);
    sort(arr, l, end);
  }
}
```

Quicksort in C

```
let rec sort  l =
  match l with [] -> []
  |(h::t) ->
     let(l,r)= List.partition ((<=) h) t in
     (sort l)@h::(sort r)
```

Quicksort in Ocaml

Why readability matters…

```
sort=:(($:@(<#[),(=#[),$:@(>#[))({~ ?@#))^: (1:<#)
```

Quicksort in J

Say hello to OCaml

```
let rec sort  l =
  match l with [] -> []
  |(h::t) ->
     let (l,r)= List.partition ((<=) h) t in
     (sort l)@h::(sort r)
```

Quicksort in OCaml

Plan (next 4 weeks)

1. Fast forward
   - Rapid introduction to what's in OCaml

2. Rewind

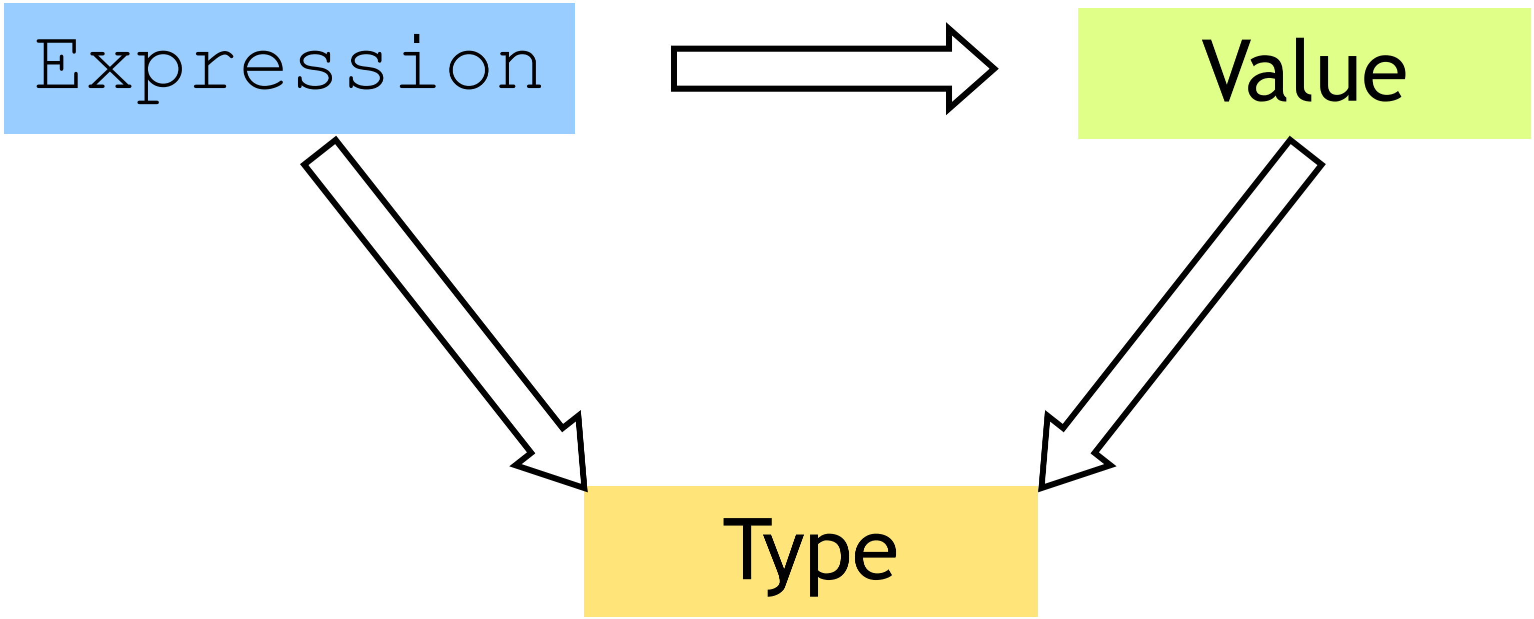
3. Slow motion
   - Go over the pieces individually

History, Variants

"Meta Language"

- Designed by Robin Milner @ Edinburgh
- Language to manipulate Theorems/Proofs
- Several dialects:
  - Standard" ML (of New Jersey)
    - Original syntax
  - "O'Caml: The PL for the discerning hacker"
    - French dialect with support for objects
    - State-of-the-art
    - Extensive library, tool, user support
    - (.NET)

ML’s holy trinity



- Everything is an expression
- Everything has a value
- Everything has a type

Interacting with ML

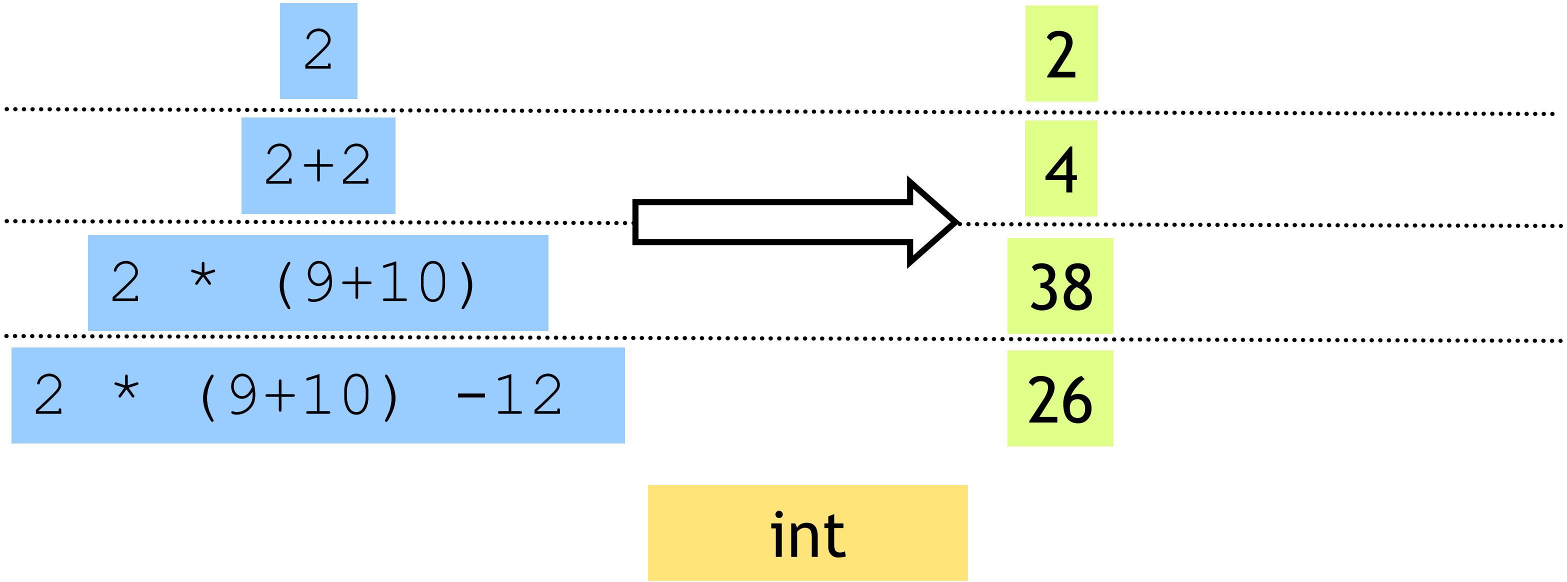
“Read-Eval-Print” Loop

Repeat:

1. System reads expression **e**
2. System evaluates **e** to get value **v**
3. System prints value **v** and type **t**

What are these expressions, values and types ?

Base type: Integers



```
2
2+2
2 * (9+10)
2 * (9+10) -12
```

2

4

38

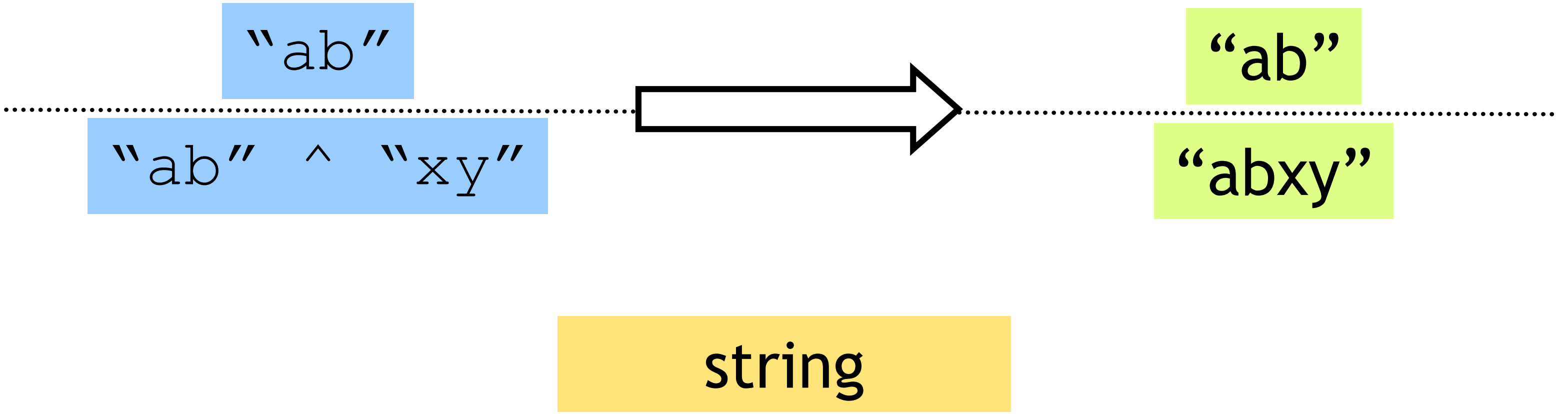
26

int

Complex expressions using “operators”: *(why the quotes ?)*

- +, -, *
- div, mod

Base type: Strings



`"ab"`

`"ab" ^ "xy"`

"ab"

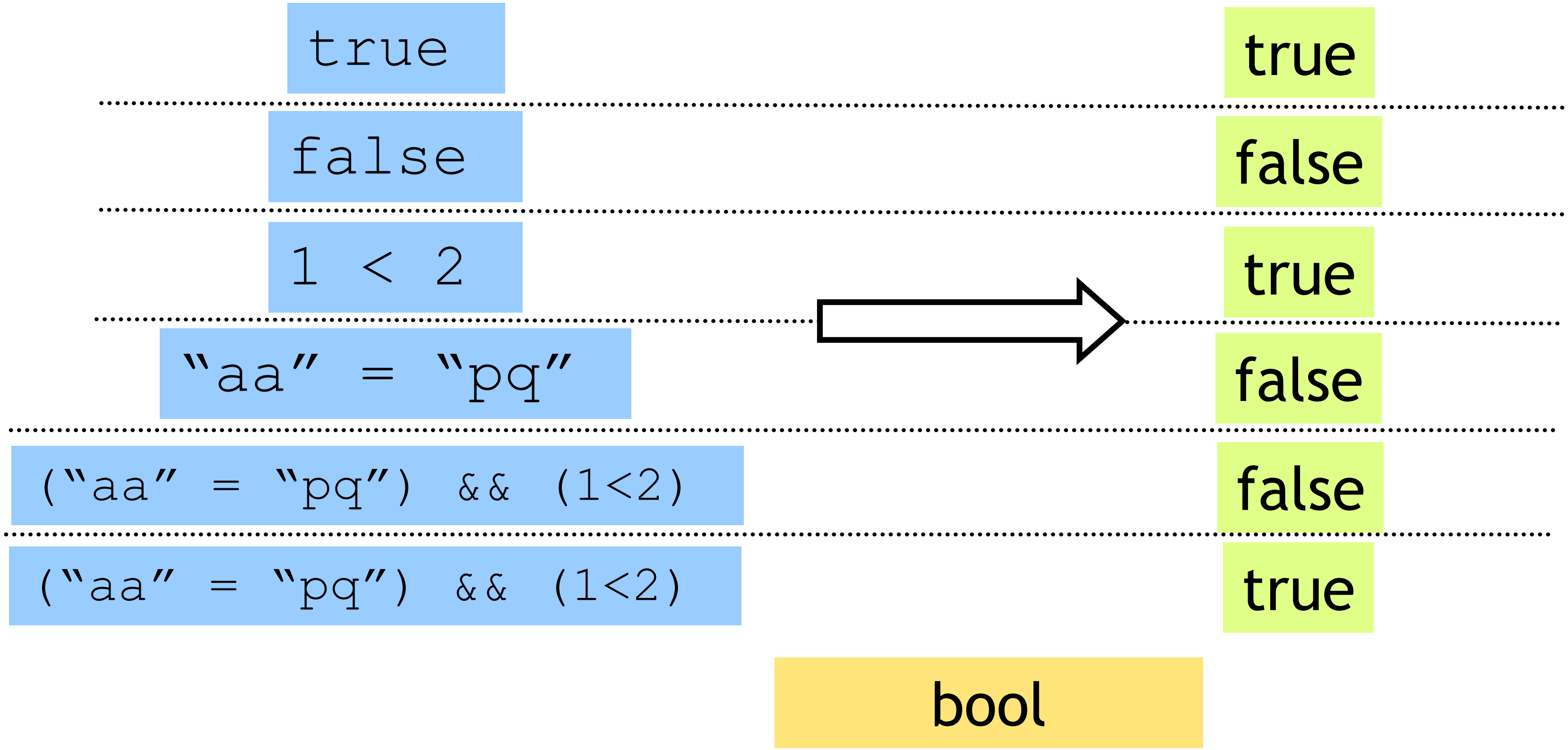
"abxy"

string

Complex expressions using “operators”: *(why the quotes ?)*

- Concatenation ^

Base type: Booleans



```
true                              true
false                             false
1 < 2                             true
"aa" = "pq"             ⇒         false
("aa" = "pq") && (1<2)            false
("aa" = "pq") && (1<2)            true
```

bool

Complex expressions using "operators":

- "Relations": = , <, <=, >=
- &&, ||, not

Type Errors

```
(2+3) || (“a” = “b”)
```

```
“pq” ^ 9
```

```
(2 + “a”)
```

Untypable expression is rejected

- No casting or coercing
- Fancy algorithm to catch errors
- ML’s single most powerful feature

Complex types: Product (tuples)

```
(2+2 , 7>8);
```

⇒ (4,false)

int * bool

Complex types: Product (tuples)

`(9-3,“ab”^“cd”,(2+2 ,7>8))` ⇒ (6, “abcd”,(4,false))

(int * string * (int * bool))

- Triples,…
- Nesting:
  - Everything is an expression, nest tuples in tuples

Complex types: Lists

`[];`	[]	’a list
`[1;2;3];`	[1;2;3]	int list
`[1+1;2+2;3+3;4+4];`	[2;4;6;8]	int list
`[“a”;“b”; “c”^“d”];`	[“a”;“b”; “cd”]	string list
`[(1,“a”^“b”);(3+4,“c”)];`	[(1,“ab”);(7,“c”)]	(int*string) list
`[[1];[2;3];[4;5;6]];`	[[1];[2;3];[4;5;6]];	(int list) list

- Unbounded size
- Can have lists of anything
- But…

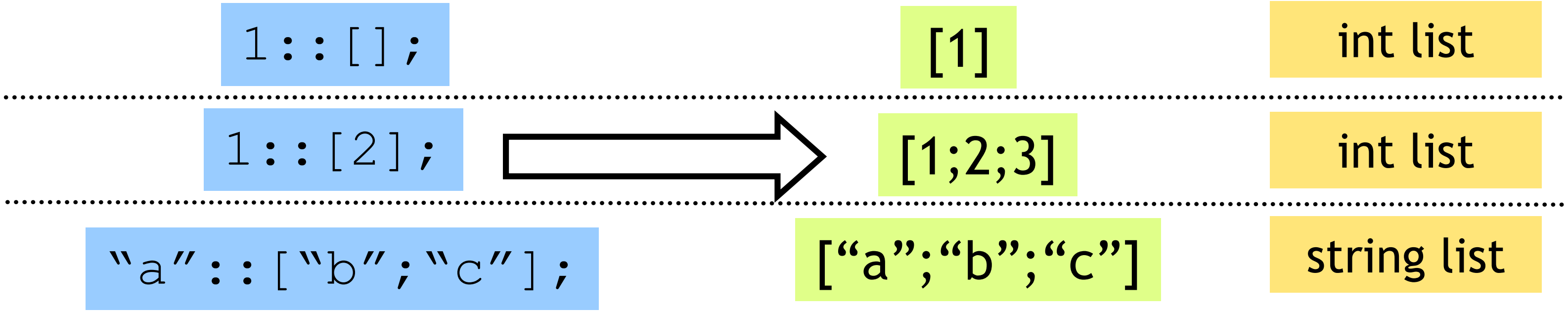
Complex types: Lists

```
[1; “pq”];
```

All elements must have same type

Complex types: Lists

List operator “Cons” `::`



`1::[];`	[1]	int list
`1::[2];`	[1;2;3]	int list
`“a”::[“b”;“c”];`	[“a”;“b”;“c”]	string list

Can only “cons” element to a list of same type

```
1::[“b”; “cd”];
```

Complex types: Lists

List operator “Append” @

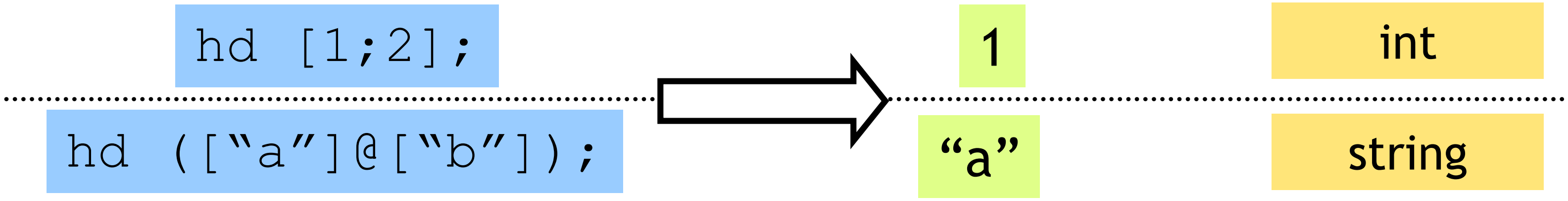
`[1;2]@[3;4;5];`	[1;2;3;4;5]	int list
`[“a”]@[“b”];`	[“a”;“b”]	string list
`[]@[1];`	[1]	string list

Can only append two lists `1 @ [2;3];`

… of the same type `[1] @ [“a”;“b”];`

Complex types: Lists

List operator “head” `hd`



```
hd [1;2];
```

1

int

```
hd ([“a”]@[“b”]);
```

“a”

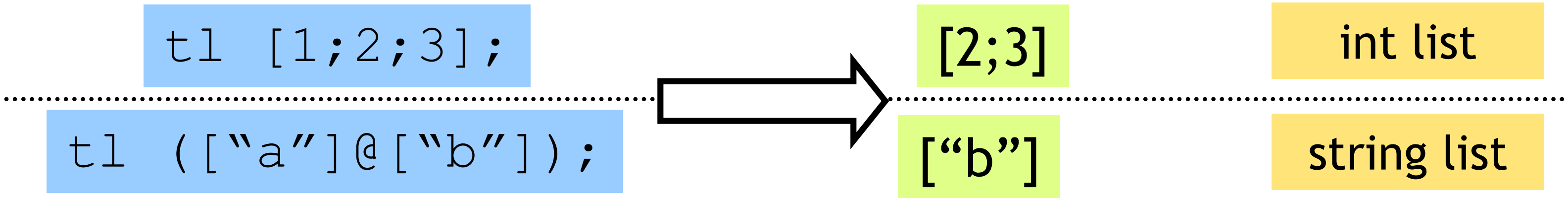
string

Only take the head a nonempty list

```
hd [];
```

Complex types: Lists

List operator “tail” tl



```
tl [1;2;3];
```

[2;3]

int list

```
tl ([“a”]@[“b”]);
```

[“b”]

string list

Only take the tail of nonempty list `tl [];`

Recap: Tuples vs. Lists ?

What’s the difference ?

Recap: Tuples vs. Lists ?

What's the difference ?

- Tuples:
  - Different types, but fixed number:

    (3, "abcd") (int * string)

    - pair = 2 elts

    (3, "abcd",(3.5,4.2)) (int * string * (real * real))

    - triple = 3 elts
- Lists:
  - Same type, unbounded number:

    [3;4;5;6;7] int list
- Syntax:
  - Tuples = comma Lists = semicolon

So far, a fancy calculator…

… what do we need next ?

Variables and bindings

```
let x = e;
```

“Bind the value of expression `e`

to the variable `x`”

```
# let x = 2+2;;
val x : int = 4
```

Variables and bindings

Later declared expressions can use `x`

- Most recent “bound” value used for evaluation

```
# let x = 2+2;;
val x : int = 4
# let y = x * x * x;;
val y : int = 64
# let z = [x;y;x+y];;
val z : int list = [4;64;68]
#
```

Variables and bindings

Undeclared variables
(i.e. without a value binding)
are not accepted !

```
# let p = a + 1;
Characters 8-9:
  let p = a + 1 ;;
          ^
Unbound value a
```

Catches many bugs due to typos

Local bindings

… for expressions using “temporary” variables

```
let
  tempVar = x + 2 * y
in
  tempVar * tempVar
;;
```

⇒ 17424 int

- `tempVar` is bound only inside expr body from `in` … `;;`
- Not visible (“in scope”) outside

Binding by Pattern-Matching

Simultaneously bind several variables

```
# let (x,y,z) = (2+3,“a”^“b”, 1::[2]);;
val x : int = 5
val y : string = “ab”
val z : int list = [1;2]
```

Binding by Pattern-Matching

But what of:

```
# let h::t = [1;2;3];;
Warning P: this pattern-matching not exhaustive.
val h : int = 1
val t : int list = [2,3]
```

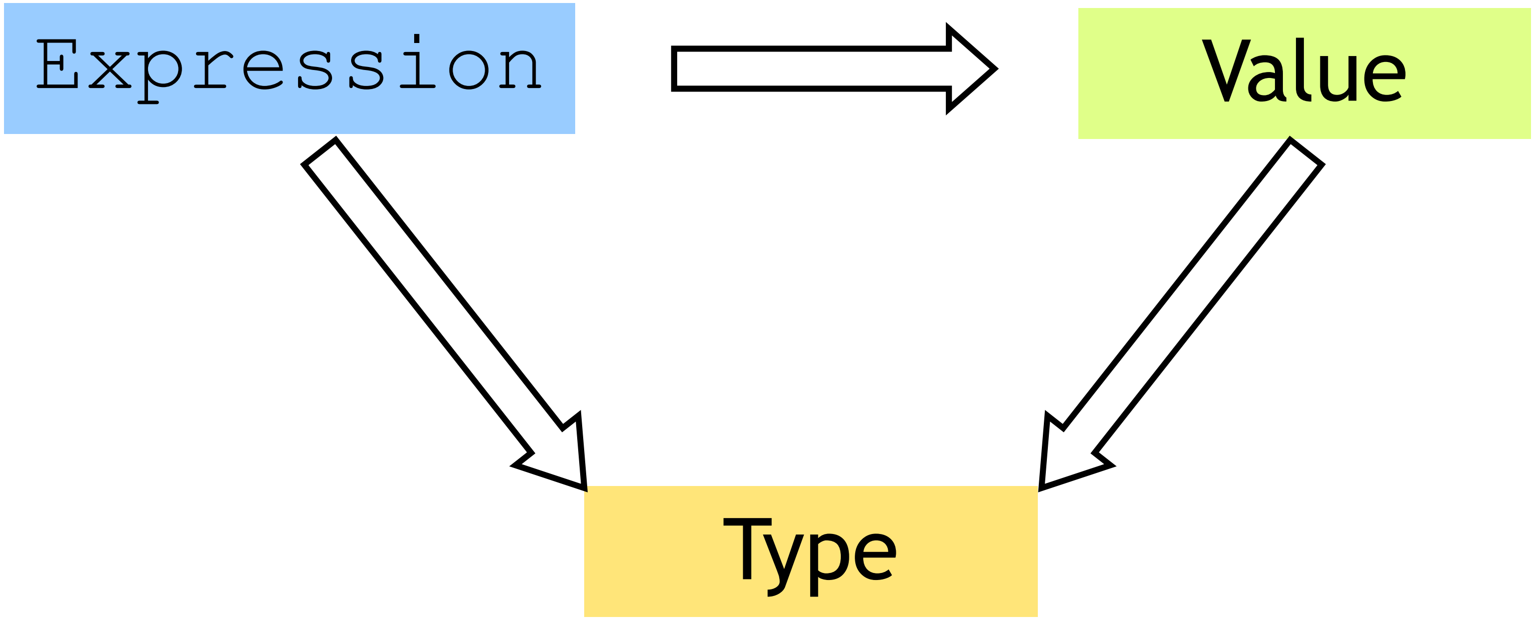
Why is it whining ?

```
# let h::t = [];
Exception: Match_failure
# let l = [1;2;3];
val l = [1;2;3]: list
- val h::t = l;
Warning: Binding not exhaustive
val h = 1 : int
val t = [2,3] : int
```

In general l may be empty (match failure!)

Another useful early warning

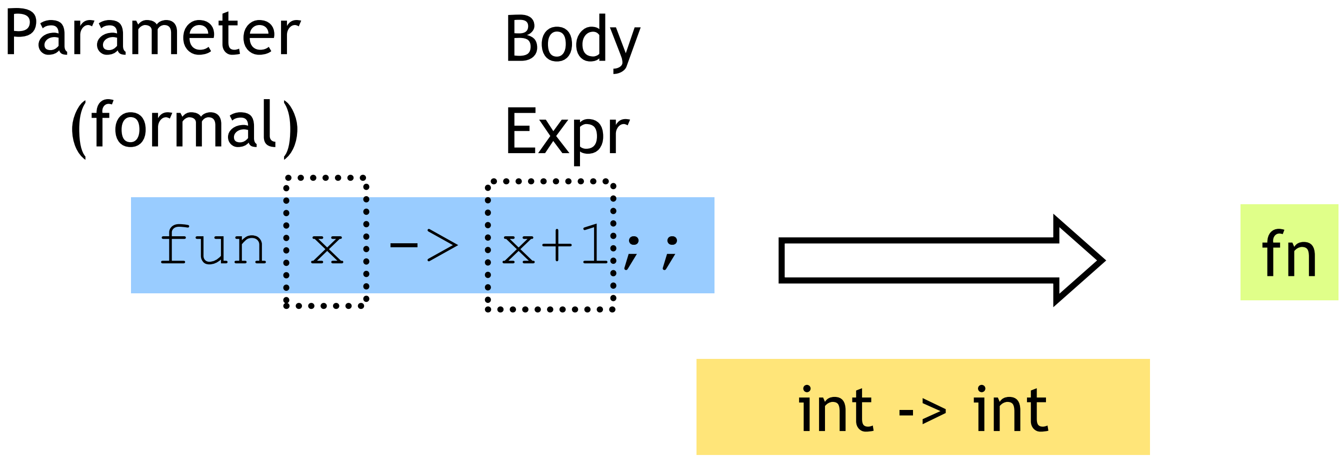
Next : functions, but remember ...



Everything is an expression
Everything has a value
Everything has a type

A function is ...

Complex types: Functions!



Parameter (formal)

Body Expr

fun x -> x+1;;

fn

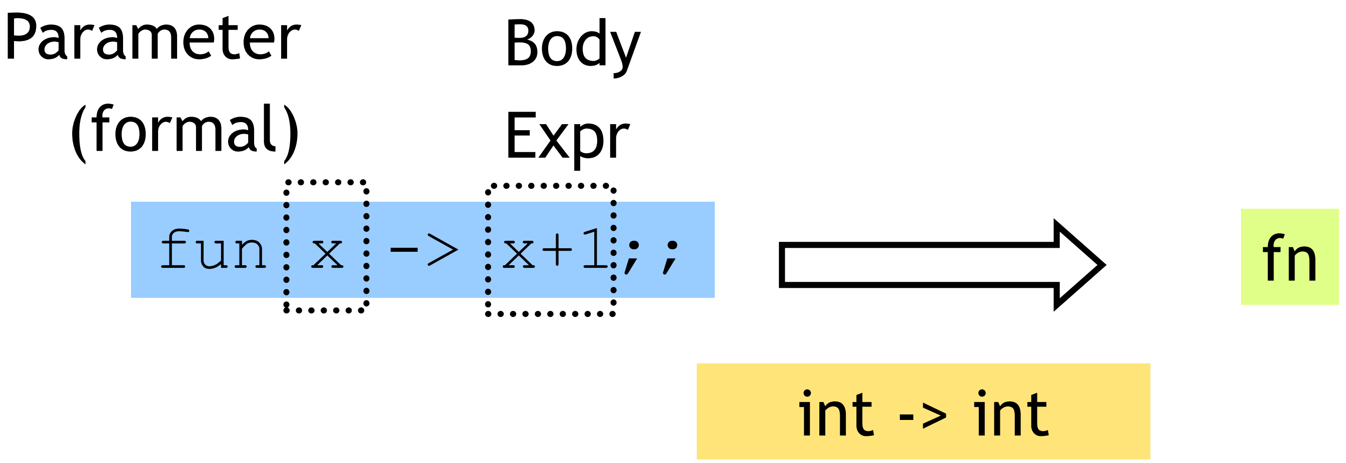
int -> int

```
# let inc = fun x -> x+1 ;
val inc : int -> int = fn
# inc 0;
val it : int = 1
# inc 10;
val it : int = 11
```

How a call ("application") is evaluated:

1. Evaluate argument
2. Bind formal to arg value
3. Evaluate "Body expr"

A Problem



Parameter (formal)

Body Expr

```
fun x -> x+1;;
```

fn

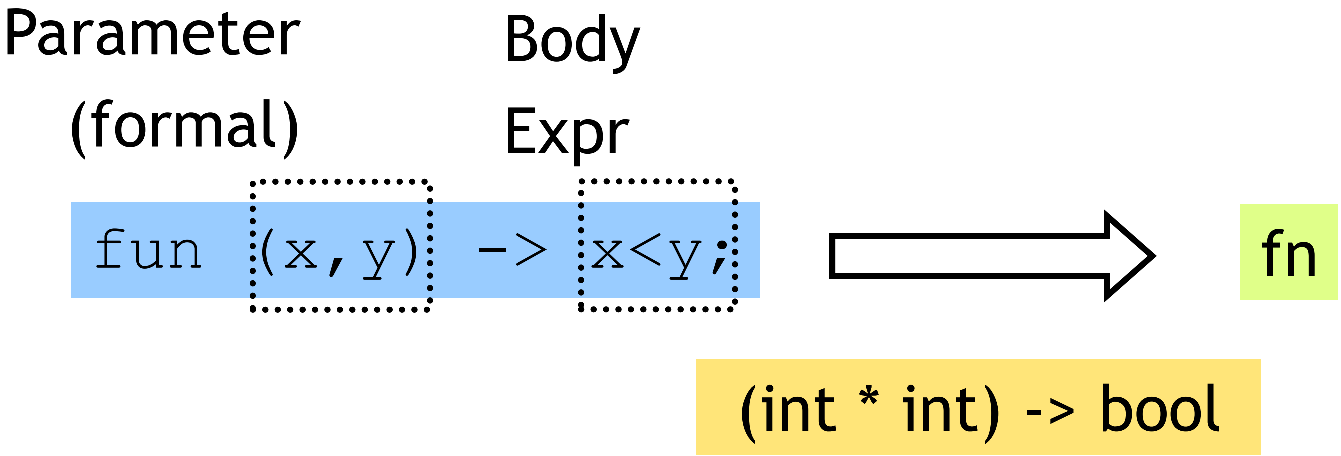
int -> int

Can functions only have a single parameter ?

How a call (“application”) is evaluated:

1. Evaluate argument
2. Bind formal to arg value
3. Evaluate “Body expr”

A Solution: Simultaneous Binding



Parameter (formal)

Body Expr

```
fun (x,y) -> x<y;
```

fn

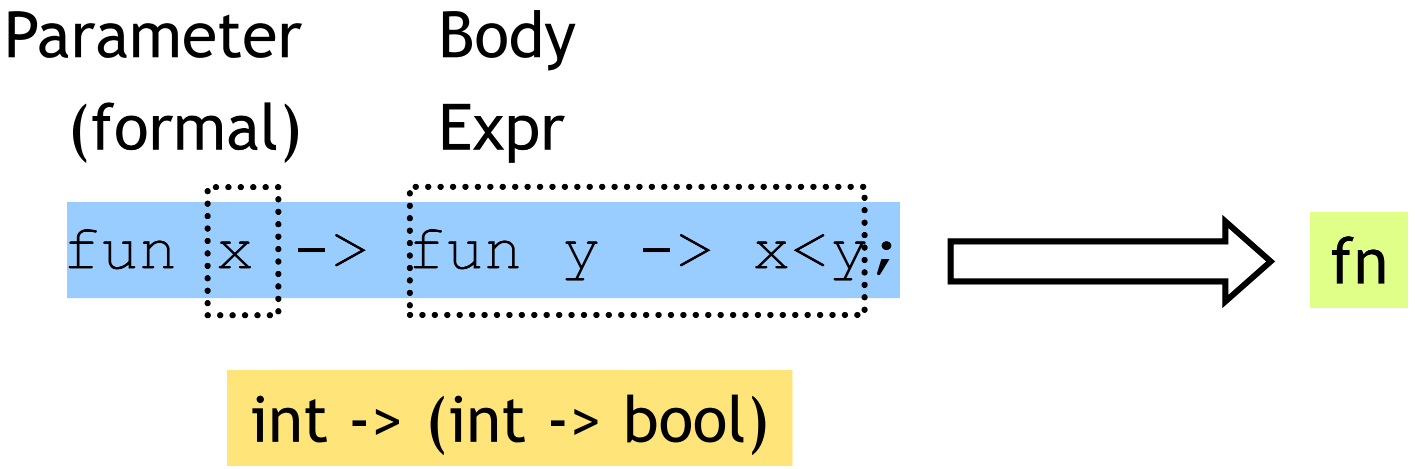
(int * int) -> bool

Can functions only have a single parameter ?

How a call (“application”) is evaluated:

1. Evaluate argument
2. Bind formal to arg value
3. Evaluate “Body expr”

Another Solution



Parameter (formal)

Body Expr

```
fun x -> fun y -> x<y;
```

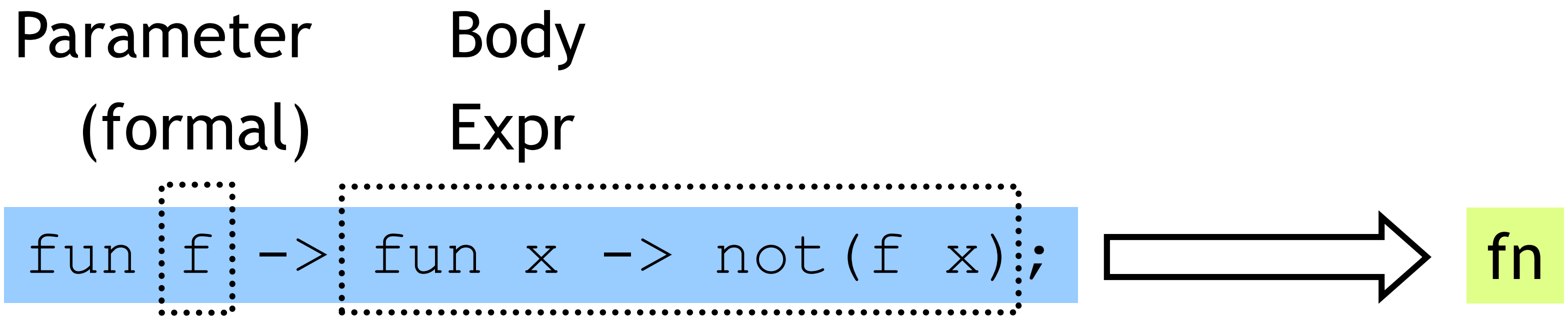
fn

int -> (int -> bool)

Whoa! A function can return a function

```
# let lt = fun x -> fn y -> x < y ;
val lt : int -> int -> bool = fn
# let is5Lt = lt 5;
val is5lt : int -> bool = fn;
# is5lt 10;
val it : bool = true;
# is5lt 2;
val it : bool = false;
```

And how about…



Parameter (formal)

Body Expr

```
fun f -> fun x -> not(f x);
```

fn

(’a ->bool) -> (’a -> bool)

A function can also take a function argument

```
# let neg = fun f -> fun x -> not (f x);
val lt : int -> int -> bool = fn
# let is5gte = neg is5lt;
val is5gte : int -> bool = fn
# is5gte 10;
val it : bool = false;
# is5gte 2;
val it : bool = true;
(*…odd, even …*)
```

A shorthand for function binding

```
# let neg = fun f -> fun x -> not (f x);
…
# let neg f x = not (f x);
val neg : int -> int -> bool = fn

# let is5gte = neg is5lt;
val is5gte : int -> bool = fn;
# is5gte 10;
val it : bool = false;
# is5gte 2;
val it : bool = true;
```

Put it together: a “filter” function

If arg “matches”
this pattern…

…then use
this Body Expr

```
- let rec filter f l =
       match l with
       []  -> []
     | (h::t)->  if f h then h::(filter f t)
                 else (filter f t);;

val filter : ('a->bool)->'a list->'a list = fn

# let list1 = [1,31,12,4,7,2,10];;
# filter is5lt list1 ;;
val it : int list = [31,12,7,10]
# filter is5gte list1;;
val it : int list = [1,2,10]
# filter even list1;;
val it : int list = [12,4,2,10]
```

Put it together: a “partition” function

```
# let partition f l = (filter f l, filter (neg f) l);
val partition :('a->bool)->'a list->'a list * 'a list = fn



# let list1 = [1,31,12,4,7,2,10];
- …
# partition is5lt list1 ;
val it : (int list * int list) = ([31,12,7,10],[1,2,10])

# partition even list1;
val it : (int list * int list) = ([12,4,2,10],[1,31,7])
```

A little trick …

```
# 2 <= 3;; …
val it : bool = true
# “ba” <= “ab”;;
val it : bool = false

# let lt = (<) ;;
val it : ‘a -> ‘a -> bool = fn

# lt 2 3;;
val it : bool = true;
# lt “ba” “ab” ;;
val it : bool = false;
```

```
# let is5Lt = lt 5;
val is5lt : int -> bool = fn;
# is5lt 10;
val it : bool = true;
# is5lt 2;
val it : bool = false;
```

Put it together: a “quicksort” function

```
let rec sort l =
  match l with
    [] -> []
  | (h::t) ->
     let (l,r) = partition ((<) h) t in
       (sort l)@(h::(sort r))
     ;;
```