CSE 341 : Programming Languages

Lecture 3
Local Bindings, Options, Purity

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Why are we here?

*To **work together** to free our minds from the shackles of imperative programming.*

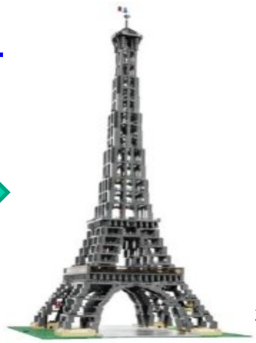
What is an ML program?

A sequence of bindings from names to expressions.

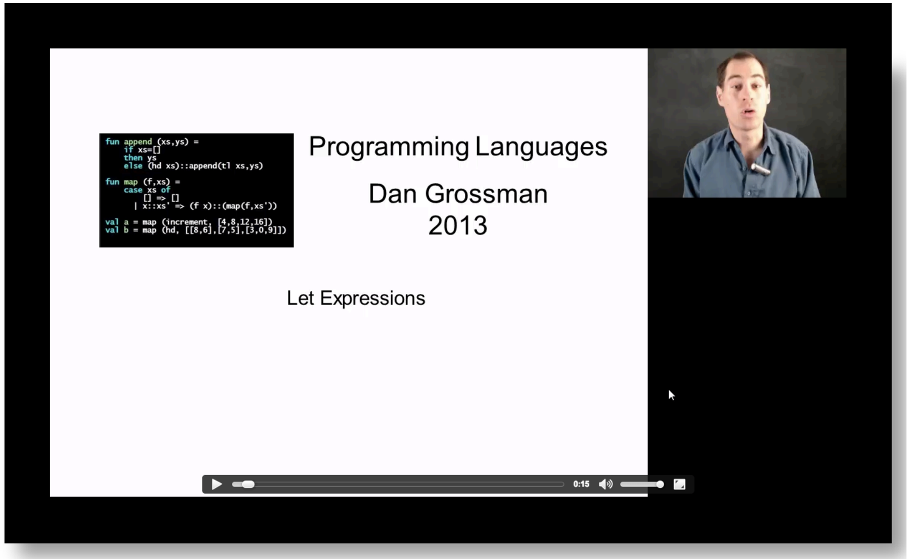
Build powerful progs by composing simple constructs.

Build rich exprs from simple exprs.

Build rich types from simple types.



Preparing for Class: Watch le Videos!



SML Team Warm-Up

```
- fact 0;
val it = 1 : int
- fact 1;
val it = 1 : int
- fact 2;
val it = 2 : int
- fact 3;
val it = 6 : int
- fact 4;
val it = 24 : int
- fact 5;
val it = 120 : int
- fact 6;
val it = 720 : int
- fact 7;
val it = 5040 : int
```


Review

Huge progress already on the core pieces of ML:

- Types: `int bool unit t1*…*tn t list t1*…*tn->t`
  - Types "nest" (each `t` above can be itself a compound type)
- Variables, environments, and basic expressions
- Functions
  - Build: `fun x0 (x1:t1, …, xn:tn) = e`
  - Use: `e0 (e1, …, en)`
- Tuples
  - Build: `(e1, …, en)`
  - Use: `#1 e, #2 e, …`
- Lists
  - Build: `[] e1::e2`
  - Use: `null e hd e tl e`

Today

- The big thing we need: local bindings
  - For style and convenience
  - A big but natural idea: nested function bindings
  - For efficiency (***not*** "just a little faster")
- One last feature for last problem of homework 1: options
- Why not having mutation (assignment statements) is a valuable language feature
  - No need for you to keep track of sharing/aliasing, which Java programmers must obsess about

Let-expressions

3 questions:

- Syntax: `let b1 b2 … bn in e end`
  - Each ***bi*** is any *binding* and ***e*** is any *expression*
- Type-checking: Type-check each ***bi*** and ***e*** in a static environment that includes the previous bindings.
  Type of whole let-expression is the type of ***e***.
- Evaluation: Evaluate each ***bi*** and ***e*** in a dynamic environment that includes the previous bindings.
  Result of whole let-expression is result of evaluating ***e***.

It is an expression

A let-expression is ***just an expression***, so we can use it ***anywhere*** an expression can go

Silly examples

```
fun silly1 (z : int) =
    let val x = if z > 0 then z else 34
        val y = x+z+9
    in
        if x > y then x*2 else y*y
    end
fun silly2 () =
    let val x = 1
    in
        (let val x = 2 in x+1 end) +
        (let val y = x+2 in y+1 end)
    end
```

`silly2` is poor style but shows let-expressions are expressions

- Can also use them in function-call arguments, if branches, etc.
- Also notice shadowing

What's new

- What's new is ***scope***: where a binding is in the environment
  - *In* later bindings and body of the let-expression
    - (Unless a later or nested binding shadows it)
  - *Only in* later bindings and body of the let-expression
- *Nothing else is new:*
  - Can put any binding we want, even function bindings
  - Type-check and evaluate just like at "top-level"

Any binding

According to our rules for let-expressions, we can define functions inside any let-expression

```
let b1 b2 … bn in e end
```

This is a natural idea, and often good style

(Inferior) Example

```
fun countup_from1 (x : int) =
    let fun count (from : int, to : int) =
            if from = to
            then to :: []
            else from :: count(from+1,to)
    in
        count (1,x)
    end
```

- This shows how to use a local function binding, but:
  - Better version on next slide
  - `count` might be useful elsewhere

Better:

```
fun countup_from1_better (x : int) =
    let fun count (from : int) =
            if from = x
            then x :: []
            else from :: count(from+1)
    in
        count 1
    end
```

- Functions can use bindings in the environment where they are defined:
  - Bindings from “outer” environments
    - Such as parameters to the outer function
  - Earlier bindings in the let-expression
- Unnecessary parameters are usually bad style
  - Like `to` in previous example

Nested functions: style

- Good style to define helper functions inside the functions they help if they are:
  - Unlikely to be useful elsewhere
  - Likely to be misused if available elsewhere
  - Likely to be changed or removed later
- A fundamental trade-off in code design: reusing code saves effort and avoids bugs, but makes the reused code harder to change later

Avoid repeated recursion

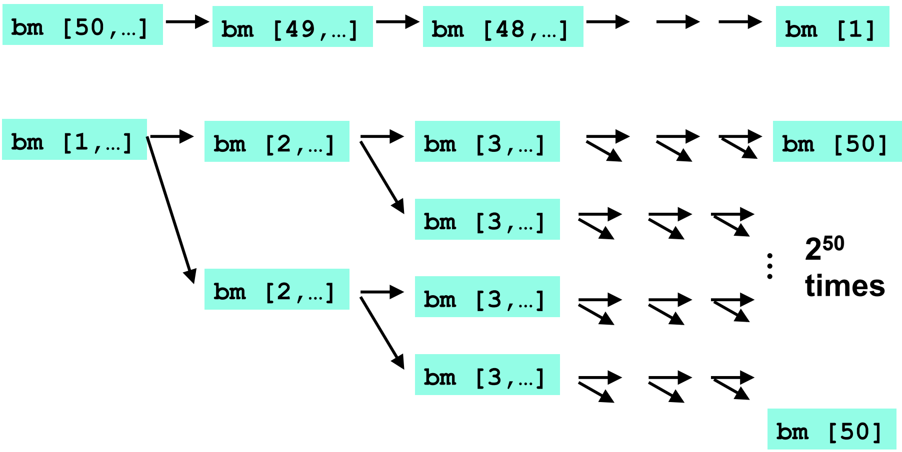
Consider this code and the recursive calls it makes

- Don’t worry about calls to `null`, `hd`, and `tl` because they do a small constant amount of work

```
fun bad_max (xs : int list) =
    if null xs
    then 0 (* horrible style; fix later *)
    else if null (tl xs)
    then hd xs
    else if hd xs > bad_max (tl xs)
    then hd xs
    else bad_max (tl xs)

val x = bad_max [50,49,…,1]
val y = bad_max [1,2,…,50]
```

Fast vs. unusable

```
if hd xs > bad_max (tl xs)
then hd xs
else bad_max (tl xs)
```



Math never lies

Suppose one **bad_max** call's if-then-else logic and calls to **hd**, **null**, **tl** take 10^{-7} seconds

- Then **bad_max [50,49,…,1]** takes 50×10^{-7} seconds
- And **bad_max [1,2,…,50]** takes 1.12×10^{8} seconds
  - (over 3.5 years)
  - **bad_max [1,2,…,55]** takes over 1 century
  - Buying a faster computer won't help much ☺

The key is not to do repeated work that might do repeated work that might do…

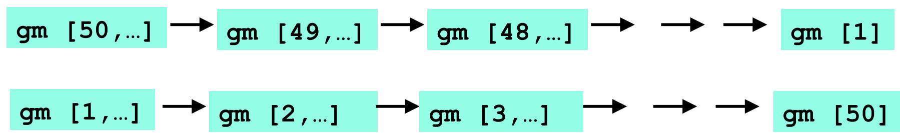
- Saving recursive results in local bindings is essential…

Efficient max

```
fun good_max (xs : int list) =
    if null xs
    then 0 (* horrible style; fix later *)
    else if null (tl xs)
    then hd xs
    else
        let val tl_ans = good_max(tl xs)
        in
            if hd xs > tl_ans
            then hd xs
            else tl_ans
        end
```

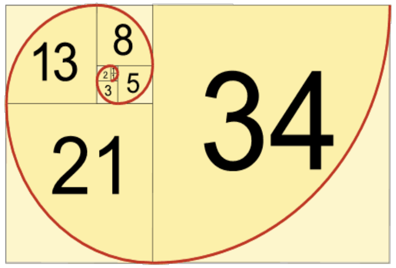

Fast vs. fast

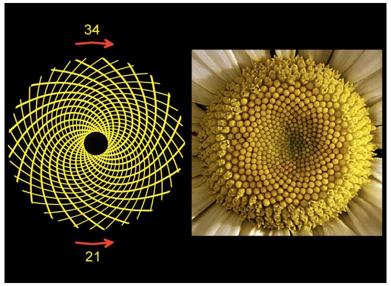
```
let val tl_ans = good_max(tl xs)
in
    if hd xs > tl_ans
    then hd xs
    else tl_ans
end
```



Team SML Practice

```
- fib 0;
val it = 0 : int
- fib 1;
val it = 1 : int
- fib 2;
val it = 1 : int
- fib 3;
val it = 2 : int
- fib 4;
val it = 3 : int
- fib 5;
val it = 5 : int
- fib 6;
val it = 8 : int
- fib 7;
val it = 13 : int
```





Options

- `t option` is a type for any type `t`
  - (much like `t list`, but a different type, not a list)

Building:

- `NONE` has type `'a option` (much like `[]` has type `'a list`)
- `SOME e` has type `t option` if `e` has type `t` (much like `e::[]`)

Accessing:

- `isSome` has type `'a option -> bool`
- `valOf` has type `'a option -> 'a` (exception if given `NONE`)

Example

```
fun better_max (xs : int list) =
    if null xs
    then NONE
    else
        let val tl_ans = better_max(tl xs)
        in
            if isSome tl_ans
               andalso valOf tl_ans > hd xs
            then tl_ans
            else SOME (hd xs)
        end
```

```
val better_max = fn : int list -> int option
```

- Nothing wrong with this, but as a matter of style might prefer not to do so much useless "`valOf`" in the recursion

Example variation

```
fun better_max2 (xs : int list) =
    if null xs
    then NONE
    else let (* ok to assume xs nonempty b/c local *)
             fun max_nonempty (xs : int list) =
               if null (tl xs)
               then hd xs
               else
                  let val tl_ans = max_nonempty(tl xs)
                  in
                    if hd xs > tl_ans
                    then hd xs
                    else tl_ans
                  end
         in
             SOME (max_nonempty xs)
         end
```

Cannot tell if you copy

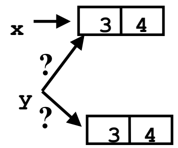
```
fun sort_pair (pr : int * int) =
  if #1 pr < #2 pr
  then pr
  else (#2 pr, #1 pr)

fun sort_pair (pr : int * int) =
  if #1 pr < #2 pr
  then (#1 pr, #2 pr)
  else (#2 pr, #1 pr)
```

In ML, these two implementations of **sort_pair** are indistinguishable

- But only because tuples are immutable
- The first is better style: simpler and avoids making a new pair in the then-branch
- In languages with mutable compound data, these are different!

Suppose we had mutation…

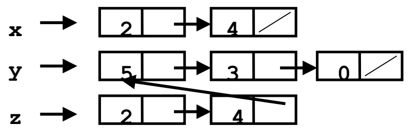
```
val x = (3,4)
val y = sort_pair x

somehow mutate #1 x to hold 5

val z = #1 y
```



- What is **z**?
  - Would depend on how we implemented **sort_pair**
    - Would have to decide carefully and document **sort_pair**
  - But without mutation, we can implement "either way"
    - No code can ever distinguish aliasing vs. identical copies
    - No need to think about aliasing: focus on other things
    - Can use aliasing, which saves space, without danger

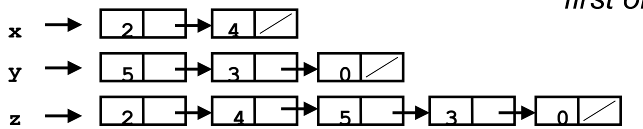
An even better example

```
fun append (xs : int list, ys : int list) =
    if null xs
    then ys
    else hd (xs) :: append (tl(xs), ys)
val x = [2,4]
val y = [5,3,0]
val z = append(x,y)
```



(can't tell, but it's the first one)

or



ML vs. Imperative Languages

- In ML, we create aliases all the time without thinking about it because it is *impossible* to tell where there is aliasing
  - Example: **tl** is constant time; does not copy rest of the list
  - So don't worry and focus on your algorithm
- In languages with mutable data (e.g., Java), programmers are *obsessed* with aliasing and object identity
  - They have to be (!) so that subsequent assignments affect the right parts of the program
  - Often crucial to make copies in just the right places
    - Consider a Java example…

Java security nightmare (bad code)

```
class ProtectedResource {
   private Resource theResource = ...;
   private String[] allowedUsers = ...;
   public String[] getAllowedUsers() {
      return allowedUsers;
   }
   public String currentUser() { ... }
   public void useTheResource() {
      for(int i=0; i < allowedUsers.length; i++) {
         if(currentUser().equals(allowedUsers[i])) {
             ... // access allowed: use it
             return;
         }
      }
      throw new IllegalAccessException();
   }
}
```


Have to make copies

The problem:

```
p.getAllowedUsers()[0] = p.currentUser();
p.useTheResource();
```

The fix:

```
public String[] getAllowedUsers() {
   … return a copy of allowedUsers …
}
```

Reference (alias) vs. copy doesn’t matter if code is immutable!