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Example

Can reuse n_times rather than defining many similar functions - Computes f(f(...f(x))) where number of calls is n

```
fun n_times (f,n,x) =
    if n=0
    then x
    else f (n_times(f,n-1,x))
fun double x = x + x
fun increment x = x + 1
val x1 = n_times(double,4,7)
val x2 = n_times(increment,4,7)
val x3 = n_times(tl,2,[4,8,12,16])
fun double_n_times (n,x) = n_times(double,n,x)
fun nth_tail (n,x) = n_times(tl,n,x)
```

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Relation to types

- Higher-order functions are often so "generic" and "reusable" that they have polymorphic types, i.e., types with type variables
- · But there are higher-order functions that are not polymorphic
- And there are non-higher-order (first-order) functions that are polymorphic
- Always a good idea to understand the type of a function, especially a higher-order function

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Types for example

fun n_times (f,n,x) =
 if n=0
 then x
 else f (n_times(f,n-1,x))

- val n_times : ('a -> 'a) * int * 'a -> 'a
 Simpler but less useful: (int -> int) * int * int -> int
- Two of our examples instantiated 'a with int
- One of our examples instantiated 'a with int list
- This *polymorphism* makes n_times more useful
- Type is *inferred* based on how arguments are used (later lecture)
 Describes which types must be exactly something (e.g., int) and which can be anything but the same (e.g., 'a)

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Polymorphism and higher-order functions

- Many higher-order functions are polymorphic because they are so reusable that some types, "can be anything"
- But some polymorphic functions are not higher-order
 Example: len : 'a list -> int
- And some higher-order functions are not polymorphic
 Example: times_until_0 : (int -> int) * int -> int

fun times_until_zero (f,x) =
 if x=0 then 0 else 1 + times_until_zero(f, f x)

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Note: Would be better with tail-recursion

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Toward anonymous functions

```
· Definitions unnecessarily at top-level are still poor style:
   fun trip x = 3 * x
   fun triple_n_times (f,x) = n_times(trip,n,x)
· So this is better (but not the best):
   fun triple_n_times (f,x) =
     let fun trip y = 3*y
     in
        n_times(trip,n,x)
     end
· And this is even smaller scope
    - It makes sense but looks weird (poor style; see next slide)
 fun triple_n_times (f,x) =
    n_times(let fun trip y = 3*y in trip end, n, x)
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                                                           11
```

Anonymous functions

This does not work: A function *binding* is not an *expression*fun triple_n_times (f,x) =
 n_times((fun trip y = 3*y), n, x)

This is the best way we were building up to: an expression form
for anonymous functions

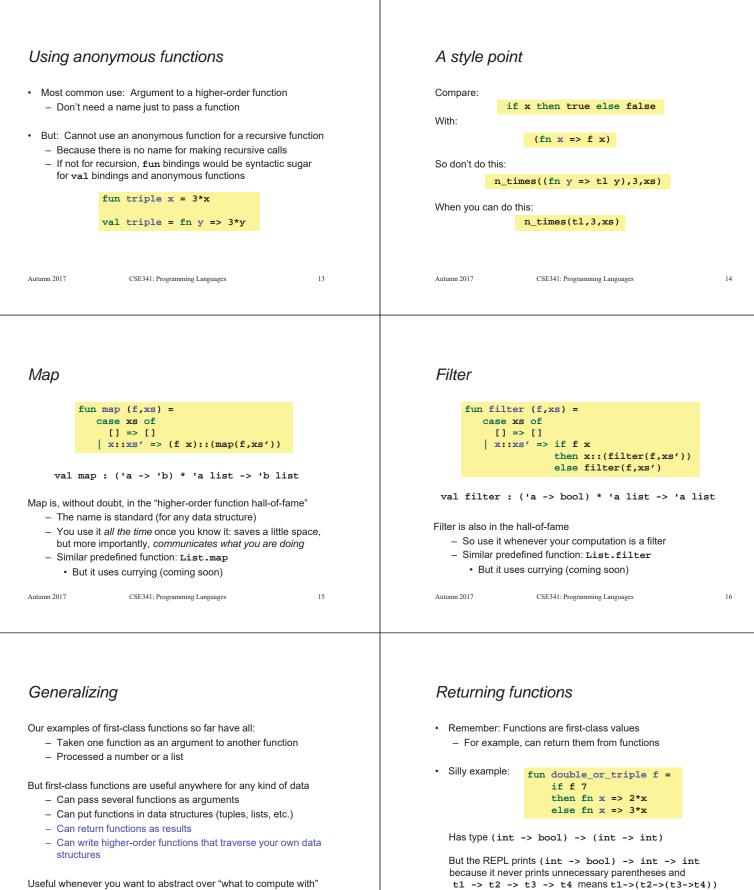
```
fun triple_n_times (f,x) =
  n_times((fn y => 3*y), n, x)
```

- Like all expression forms, can appear anywhere
- Syntax:
 - fn not fun
 - => not =
 - · no function name, just an argument pattern

```
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```

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Useful whenever you want to abstract over "what to compute with"

- No new language features

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Other data structures

- · Higher-order functions are not just for numbers and lists
- They work great for common recursive traversals over your own data structures (datatype bindings) too
- Example of a higher-order *predicate*:
 - Are all constants in an arithmetic expression even numbers?
 - Use a more general function of type (int -> bool) * exp -> bool
 - And call it with (fn $x \Rightarrow mod 2 = 0$)

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