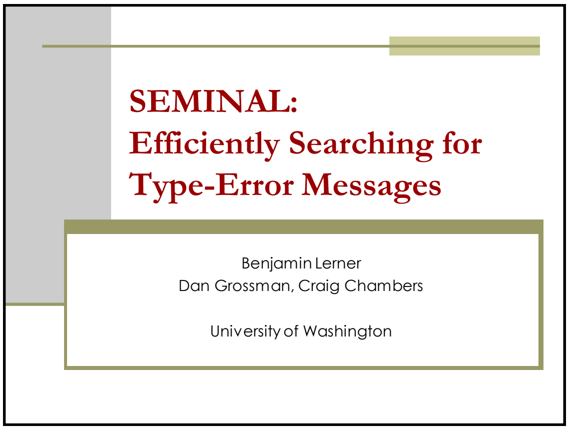

SEMINAL: Efficiently Searching for Type-Error Messages

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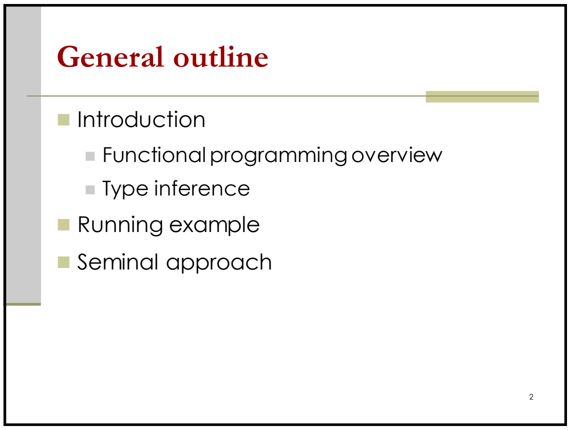
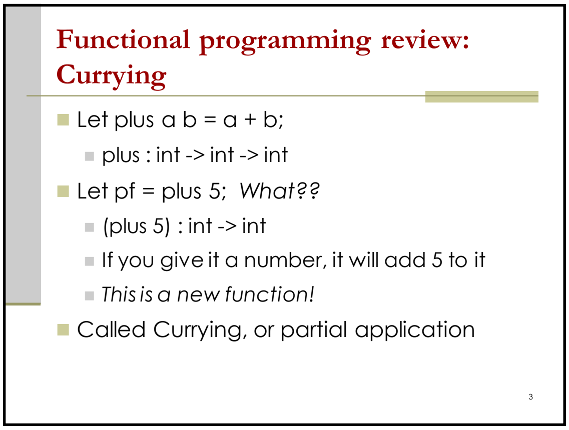


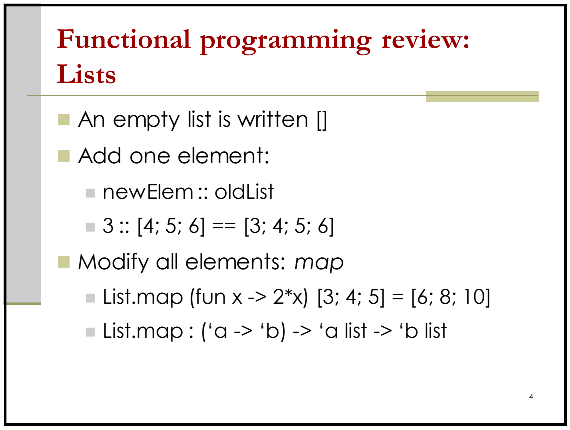
General outline

- Introduction
  - Functional programming overview
  - Type inference
- Running example
- Seminal approach



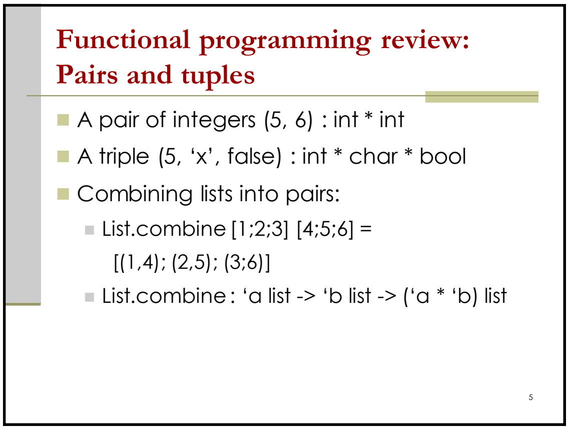
Functional programming review: Currying

- Let plus a b = a + b;
  - plus : int -> int -> int
- Let pf = plus 5; *What??*
  - (plus 5) : int -> int
  - If you give it a number, it will add 5 to it
  - *This is a new function!*
- Called Currying, or partial application



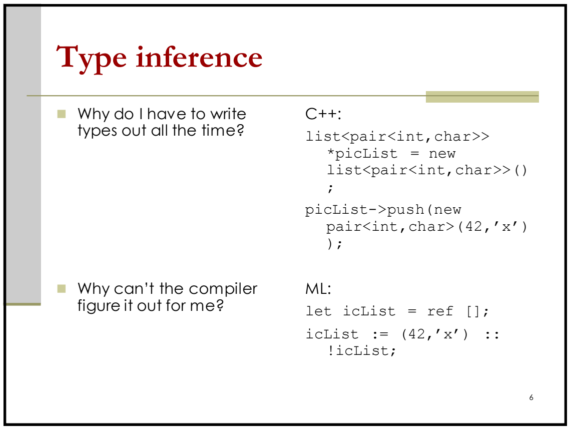
Functional programming review: Lists

- An empty list is written []
- Add one element:
  - newElem :: oldList
  - 3 :: [4; 5; 6] == [3; 4; 5; 6]
- Modify all elements: *map*
  - List.map (fun x -> 2*x) [3; 4; 5] = [6; 8; 10]
  - List.map : ('a -> 'b) -> 'a list -> 'b list



Functional programming review: Pairs and tuples

- A pair of integers (5, 6) : int * int
- A triple (5, 'x', false) : int * char * bool
- Combining lists into pairs:
  - List.combine [1;2;3] [4;5;6] =
    [(1,4); (2,5); (3;6)]
  - List.combine : 'a list -> 'b list -> ('a * 'b) list



Type inference

- Why do I have to write types out all the time?

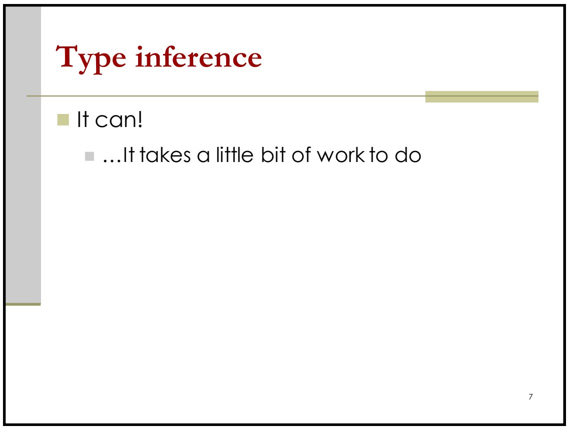
C++:

```
list<pair<int,char>>
   *picList = new
   list<pair<int,char>>()
   ;
picList->push(new
   pair<int,char>(42,'x')
   );
```

- Why can't the compiler figure it out for me?

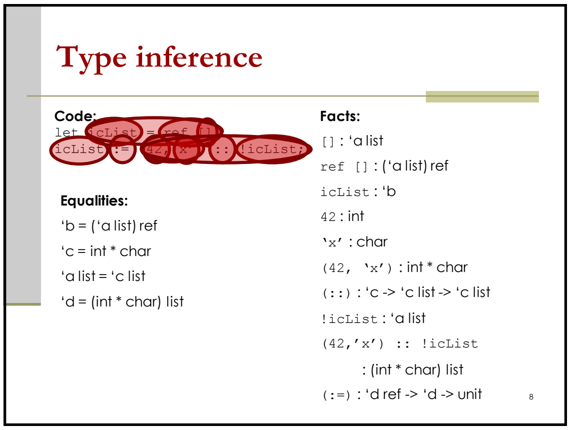
ML:

```
let icList = ref [];
icList := (42,'x') ::
   !icList;
```



Type inference

- It can!
  - …It takes a little bit of work to do



Type inference

Code:

```
let icList = ref []
icList := (42,'x') :: !icList;
```

Equalities:

'b = ('a list) ref

'c = int * char

'a list = 'c list

'd = (int * char) list

Facts:

`[]` : 'a list

`ref []` : ('a list) ref

`icList` : 'b

`42` : int

`'x'` : char

`(42, 'x')` : int * char

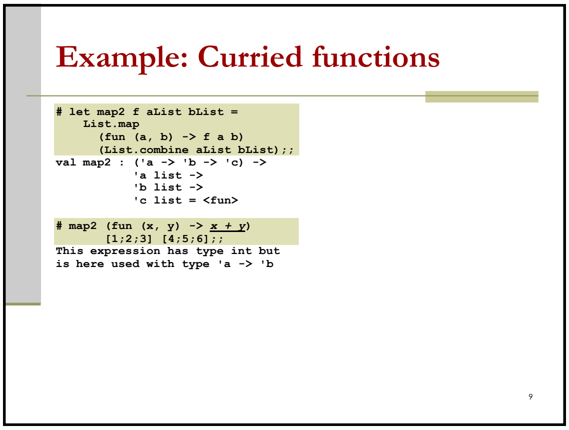
`(::)` : 'c -> 'c list -> 'c list

`!icList` : 'a list

`(42,'x') :: !icList`

: (int * char) list

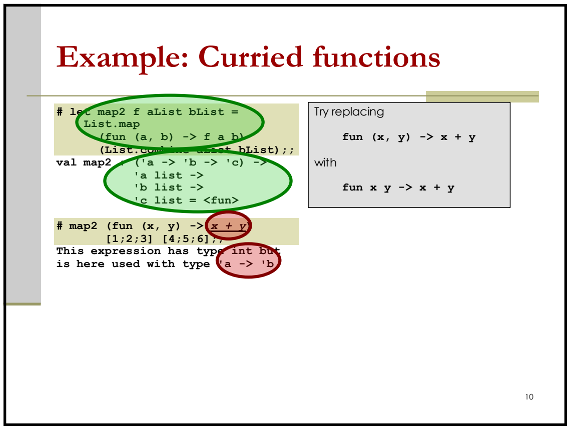
`(:=)` : 'd ref -> 'd -> unit



Example: Curried functions

```
# let map2 f aList bList =
    List.map
      (fun (a, b) -> f a b)
      (List.combine aList bList);;
val map2 : ('a -> 'b -> 'c) ->
           'a list ->
           'b list ->
           'c list = <fun>

# map2 (fun (x, y) -> x + y)
       [1;2;3] [4;5;6];;
This expression has type int but
is here used with type 'a -> 'b
```



Example: Curried functions

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val map2 : ('a -> 'b -> 'c) ->
           'a list ->
           'b list ->
           'c list = <fun>

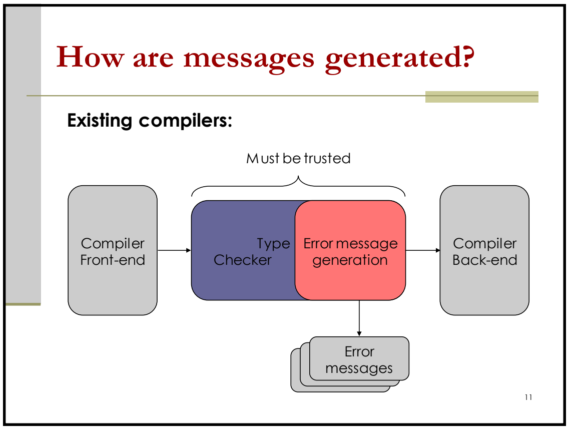
# map2 (fun (x, y) -> x + y)
       [1;2;3] [4;5;6];;
This expression has type int but
is here used with type 'a -> 'b
```

Try replacing

```
fun (x, y) -> x + y
```

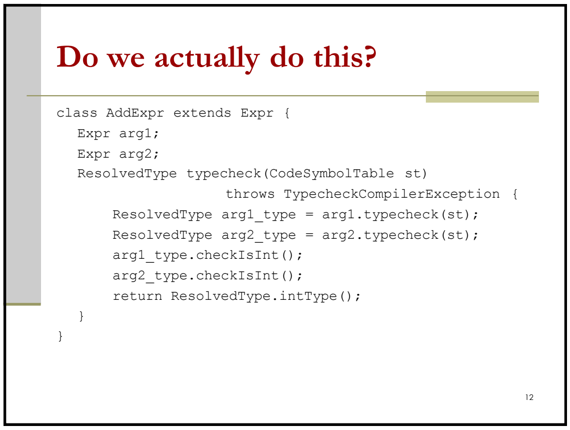
with

```
fun x y -> x + y
```



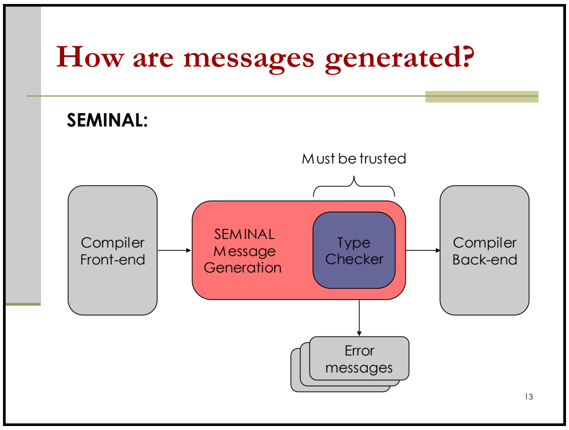
How are messages generated?

Existing compilers:



Do we actually do this?

```
class AddExpr extends Expr {
  Expr arg1;
  Expr arg2;
  ResolvedType typecheck(CodeSymbolTable st)
                    throws TypecheckCompilerException {
      ResolvedType arg1_type = arg1.typecheck(st);
      ResolvedType arg2_type = arg2.typecheck(st);
      arg1_type.checkIsInt();
      arg2_type.checkIsInt();
      return ResolvedType.intType();
  }
}
```



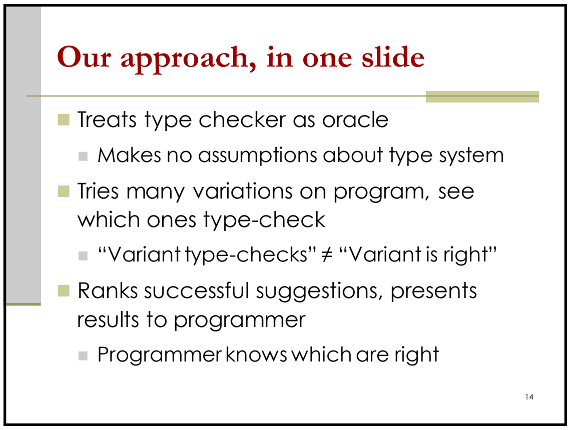
How are messages generated?

SEMINAL:

Must be trusted

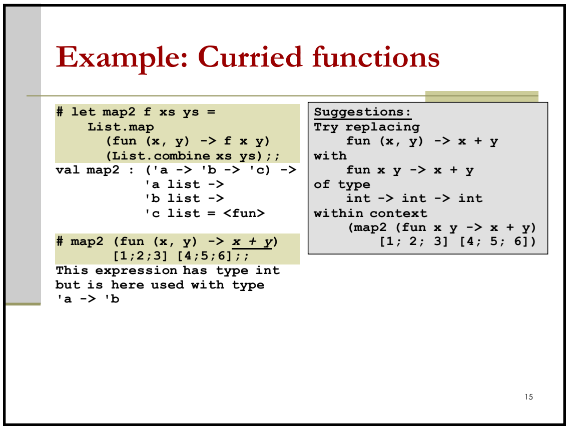
Compiler Front-end → SEMINAL Message Generation / Type Checker → Compiler Back-end

Error messages



Our approach, in one slide

- Treats type checker as oracle
  - Makes no assumptions about type system
- Tries many variations on program, see which ones type-check
  - "Variant type-checks" ≠ "Variant is right"
- Ranks successful suggestions, presents results to programmer
  - Programmer knows which are right

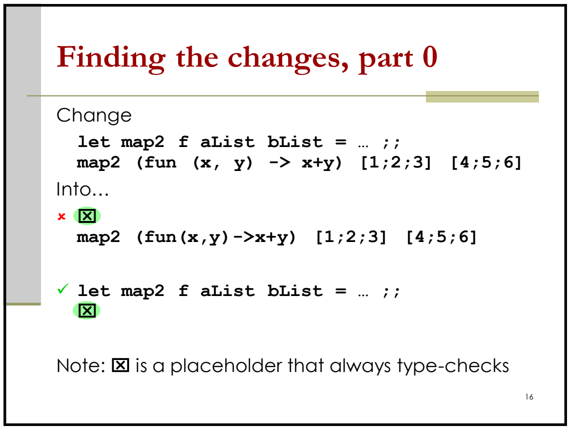


Example: Curried functions

```
# let map2 f xs ys =
    List.map
      (fun (x, y) -> f x y)
      (List.combine xs ys);;
val map2 : ('a -> 'b -> 'c) ->
           'a list ->
           'b list ->
           'c list = <fun>

# map2 (fun (x, y) -> x + y)
       [1;2;3] [4;5;6];;
This expression has type int
but is here used with type
'a -> 'b
```

```
Suggestions:
Try replacing
    fun (x, y) -> x + y
with
    fun x y -> x + y
of type
    int -> int -> int
within context
    (map2 (fun x y -> x + y)
        [1; 2; 3] [4; 5; 6])
```



Finding the changes, part 0

Change

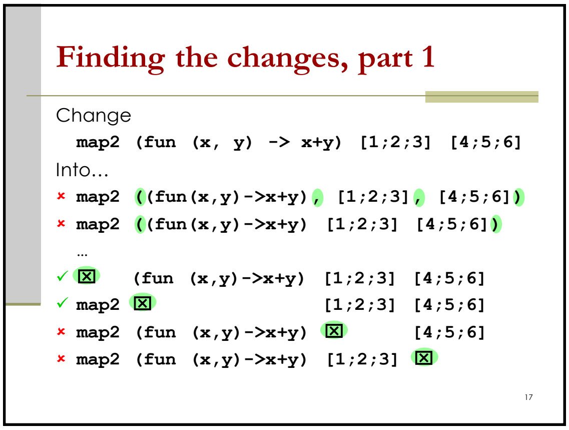
```
  let map2 f aList bList = … ;;
  map2 (fun (x, y) -> x+y) [1;2;3] [4;5;6]
```

Into…

```
✗ ☒
  map2 (fun(x,y)->x+y) [1;2;3] [4;5;6]


✓ let map2 f aList bList = … ;;
  ☒
```

Note: ☒ is a placeholder that always type-checks



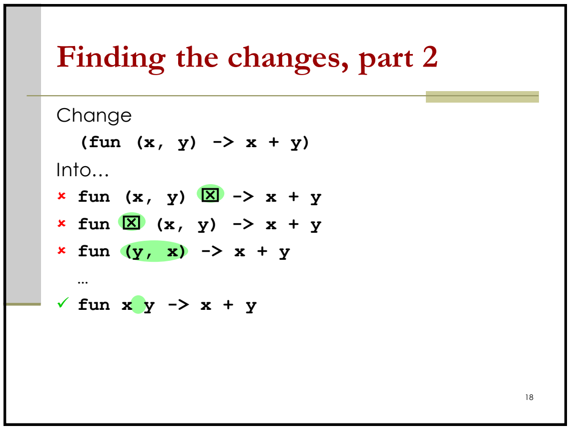
Finding the changes, part 1

Change

```
  map2 (fun (x, y) -> x+y) [1;2;3] [4;5;6]
```

Into…

```
✗ map2 ((fun(x,y)->x+y), [1;2;3], [4;5;6])
✗ map2 ((fun(x,y)->x+y) [1;2;3] [4;5;6])
  …
✓ ☒     (fun (x,y)->x+y) [1;2;3] [4;5;6]
✓ map2 ☒                 [1;2;3] [4;5;6]
✗ map2 (fun (x,y)->x+y) ☒        [4;5;6]
✗ map2 (fun (x,y)->x+y) [1;2;3] ☒
```



Finding the changes, part 2

Change

```
  (fun (x, y) -> x + y)
```

Into…

```
✗ fun (x, y) ☒ -> x + y
✗ fun ☒ (x, y) -> x + y
✗ fun (y, x) -> x + y
  …
✓ fun x y -> x + y
```

Ranking the suggestions

- Replace
  `map2 (fun (x,y)->x+y)`
  `      [1;2;3] [4;5;6]`
  with ☒
- Replace `map2`
  with ☒
- Replace `(fun (x,y)->x+y)`
  with ☒
- Replace `(fun (x,y)->x+y)`
  with `(fun x y -> x+y)`
- Prefer smaller changes over larger ones
- Prefer non-deleting changes over others

Tidying up

- Find type of replacement
  - Get this for free from TC
- Maintain surrounding context
  - Help user locate the replacement

```
Suggestions:
Try replacing
    fun (x, y) -> x + y
with
    fun x y -> x + y
of type
    int -> int -> int
within context
    (map2 (fun x y -> x + y)
          [1; 2; 3] [4; 5; 6])
```

Conclusions

- Searching for error messages works!
  - Yields useful messages as often as current compiler
  - Can be improved easily
- Good for programmers, good for compiler writers