Recap
Where We’ve Been

- recursive programming over lists, trees, etc.
- high-performance persistent data structures
  - Okasaki red-black trees
- higher-order programming (“functions as data”)
  - continuation-passing style
  - pure lambda-calculus
- combinator libraries for parsing, XML transformation, pretty printing
- functional animation (Behaviors as values)
- monadic approaches to computational effects
  - e.g., monadic treatment of session state in WASH
- advanced aspects of type systems
  - polymorphism
  - type classes and qualified types
  - type inference
- Modularity and abstraction
- Testing (randomized and unit-testing)
Where We Haven’t Been

There are many more topics that I wish we’d had time to cover...

- functional reactive programming
- concurrent functional programming
- monad transformers
- arrows
- advanced module systems (ML-style “functional programming with modules”)
- more on “programming as writing”
- much, much more on abstraction and modularity
Functional Programming in the Real World
Of course, much as we might enjoy programming in Haskell, the fact is that most of the world uses other languages and other programming paradigms (e.g., OOP).
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Of course, much as we might enjoy programming in Haskell, the fact is that most of the world uses other languages and other programming paradigms (e.g., OOP).

Q: How much of what we’ve seen this semester is transferrable to other settings?
A: Not everything, but a lot...
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There are lots of real-world settings that rely on purely functional programming

- Ericsson’s flagship AXD301 ATM switch is implemented in Erlang, a purely functional distributed language
- Google’s sawzall (designed by Unix luminary Rob Pike) is a purely functional language that allows operations such as map and fold over the entire contents of the web
In Java, it is possible to program in a purely functional style
  • Cf. FeatherWeight Java

However, in practice it is difficult; in particular, many libraries encourage an imperative style
  • e.g., Iterators, etc.

However, keeping assignments to a minimum and making the scope of mutable variables as local as possible will make most programs much more modular and robust
  • The mostly functional style

Particularly important in concurrent programs, where every piece of mutable state is an opportunity for race conditions and other nastiness.
“Vanilla Java” provides only subtype polymorphism. Using libraries for generic structures such as lists involves awkward (and statically unsafe) downcasts.

```java
interface Collection {
    public void add (Object x);
    public Iterator iterator ();
}
interface Iterator {
    public Object next ();
    public boolean hasNext ();
}

... 

LinkedList ys = new LinkedList();
ys.add("zero"); ys.add("one");
String y = (String)ys.iterator().next();
```
However, Java 1.5 (and new releases of .NET) include support for generics that are in many ways very close to the parametric polymorphism of Haskell.

```java
interface Collection<A> {
    public void add(A x);
    public Iterator<A> iterator();
}
interface Iterator<A> {
    public A next();
    public boolean hasNext();
}

LinkedList<String> ys = new LinkedList<String>();
ys.add("zero"); ys.add("one");
String y = ys.iterator().next();
```
Java does not provide *modules* as such. However, one of the most important idioms involving modules, *abstract data types*, can often be simulated using Java *interfaces*.

```haskell
-- Haskell interface:
module Stack ( T, push, pop, empty ) where

data T a = EmptyStk | Stk a (T a)
empty :: T a
push :: a -> T a -> T a
pop :: T a -> T a

-- Hasekll implementation:
push x s = Stk x s
pop (Stk _ s) = s
empty = EmptyStk
```

```java
// Java interface:
interface Stack<A>
{
    A push(A item);
    A pop();
    A peek();
    boolean empty();
}

// Java implementation:
// (too hideous to show :-)
```
Insight: “object” $\sim$ “function with multiple entry points”

I.e., objects can be used (often in somewhat clunky and verbose ways) to approximate many of the programming idioms we are used to in Haskell.

- inner classes (lexical closures)
- inheritance (the way it is used in lots of libraries)
- Subject/Observer pattern (and generalizations such as Model-View-Controller)
- see any design patterns book for many more examples
/* interface Subject is implemented by classes that encapsulate data that may change */
public interface Subject {
    public void register(Observer obs);
}

/* interface Observer is implemented by classes that need to know about changes to the data */
public interface Observer {
    public void notify(String msg);
}

E.g., a graphical widget such as a slider could implement the Subject interface, allowing anyone who is interested to register callbacks in the form of Observer objects.
Unfortunately, higher-order programming idioms cannot be used with complete freedom in Java, because tail calls are not guaranteed to be implemented as jumps by most compilers (e.g., javac).

Why?

1. compiler writers are troglodytes
2. tricky interactions with stack inspection
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Why?

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However, all is not lost:

- in many situations, stack depth will still be bounded
- more modern compilers (e.g., .NET) do a better job
- there are techniques (e.g., trampolining) for getting around these compiler limitations
Haskell’s mechanisms for datatype definitions and compact pattern matching allow complex symbolic manipulations to be written very compactly and readably.

This makes Haskell (and OCaml, Standard ML, etc.) excellent tools for certain tasks.

- E.g., you’d be crazy to write a serious compiler in a language without pattern matching!
Data types and pattern matching can be approximated (unfortunately in a somewhat verbose way) in Java.
Cf. the so-called visitor pattern.
A few important aspects of Haskell are, sadly, hard to approximate in other languages.

- Type classes (Java’s overloading is a poor substitute)
- Explicit encapsulation of computational effects (monads)
  - This is the feature of Haskell that makes it possible to define “domain-specific imperative languages”
  - E.g., it is what ensures that WASH can capture all IO actions in its session log

Fortunately, both of these ideas are getting a lot of interest in other parts of the programming languages community, so we can hope that they’ll show up more widely at some point.

- cf. garbage collection, type safety, polymorphism
• Programming is writing
• Functions are data
• Abstraction is good
• The type checker is your friend

Have a great summer!