Programming Paradigms

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- First, we survey the major paradigms
Real languages draw upon multiple paradigms

We consider pure programming paradigms

First, we survey the major paradigms

Then, we examine a subset of paradigms in detail
The Procedural Paradigm

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- Form basis of the majority of real-world programming
- The key concept: *altering a value*
  - altering variables by assignment
  - altering variables by transformation (applying multiplication)
  - altering environments (procedure call)
  - altering I/O (assign values to outputs, assigning vars to inputs)
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- The key concept: *altering a value*
  - altering variables by assignment
  - altering variables by transformation (applying multiplication)
  - altering environments (procedure call)
  - altering I/O (assign values to outputs, assigning vars to inputs)
- a.k.a imperative: you tell the program which (altering) actions to take
Procedural Sorting

- Sort an array of elements set $T$ procedurally:

```c
void naive_bubble_sort(int *T, int n) {
    for(int i=0; i< n; i++)
        for(int j=0; j<n-1; j++)
            if( T[j] < T[j+1]) {
                int tmp = T[j];
                T[j] = T[j+1];
                T[j+1] = tmp; }
}
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- We loop by repeatedly altering indices
- We sort by pair-wise altering elements that are out of order
- Original array is altered to contain new elements
Comments on Procedural Languages

▶ New computations destroy results of old computations
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- Procedure1 can inadvertently modify data that violates the assumptions of Procedure2
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  - Sequence (statements in list)
  - Conditional (if then else)
  - Iteration (for, do, while)
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- Dominant computational metaphors are:
  - Sequence (statements in list)
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- Key to understanding a pure procedural program: "How does program alter the data?"
Commonly Associated Features

Typically but not necessarily:
Commonly Associated Features

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- User is responsible for allocating space for variables
Commonly Associated Features

Typically but not necessarily:

- User is responsible for allocating space for variables
- Space is often rigidly typed - it can only be used for one type of data
Examples of Procedural Languages

How many can you name?
Examples of Procedural Languages

How many can you name?

► Assembly Languages: used to implement low-level drivers & interfaces

► Mainstream languages:
  ► Fortran (used in sciences)
  ► C (general & systems programming)
  ► ADA (used in military and research)
  ► PERL, Basic & Javascript (used in scripting and interfaces)
  ► APL, S, M: highly specialized languages for mathematics
  ► LOGO: used in children’s education

► Scripting languages: csh, bash, tcl, etc.

► Other languages: Pascal, COBOL, PL/I, Algol
Object-Oriented Paradigm

▶ Extension of procedural paradigm
Object-Oriented Paradigm

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- Emphasis is *objects* and their relationships (not processes).
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- Emphasis is objects and their relationships (not processes).
- Encapsulates procedures and associated data into unit
  - allows guarantees of invariant properties of the unit
Object-Oriented Sorting

- New class: SortedSet

```java
New class: SortedSet
```

```java
SortedSet S = new SortedSet();
S.import(T);
int max = S.first();
```
Object-Oriented Sorting

- New class: SortedSet
- Data and operations of SortedSet’s are defined together
  - Inserting and removing elements, importing sets, etc. preserve sortedness property
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- New class: SortedSet

- Data and operations of SortedSet’s are defined together
  - Inserting and removing elements, importing sets, etc. preserve sortedness property

- To sort elements, we simply insert the elements of $T$ into the SortedSet

```java
SortedSet S = new SortedSet();
S.import(T);
int max = S.first();
```
Comments on Object-Oriented Approach 1

- Underlying implementation will typically be expressed in procedural terms
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- Encapsulation can improve maintainability and verifiability
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- Procedural: sorted array can become unsorted
  - Change value of element in array
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- Objects control how data is altered

- Encapsulation can improve maintainability and verifiability

- Encapsulation can be broken by derived subclasses
Comments on Object-Oriented Approach II

- Difficult issues: multiple inheritance
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Comments on Object-Oriented Approach II

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  - Polymorphism: the same procedure (method) can be applied to various data types
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  - Garbage collection: language allocates and deallocates variables as necessary
  - Free typing: parameters and variables are not statically typed
  - Polymorphism: the same procedure (method) can be applied to various data types

- Inconsistency of polymorphic definitions can make code maintenance difficult (different objects interpret a method in very different ways)
Examples of Object-Oriented Languages

How many do you know?
Examples of Object-Oriented Languages

How many do you know?

- Java: the best known and most successful
- C++ & STL: the flexibility and efficiency (and some might say obscurity and error-prone features) of C combined with the encapsulation power of objects
- Smalltalk: the first wide-spread object-oriented language
- Eiffel: an object oriented language concerned with verification
- CLOS: common lisp object system (very powerful features including the ability to define your own notions of inheritance, accessors, etc.)
- Many languages support objects: PYTHON, Matlab
Functional Paradigm

- Computation is expressed as **functions** of data
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- In *Pure* Functional Programming there are
  - No explicit assignment or “variables”
  - No explicit control structures such as IF, FOR or WHILE
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- In Pure Functional Programming there are
  - No explicit assignment or “variables”
  - No explicit control structures such as IF, FOR or WHILE
- Functional languages are Turing equivalent to procedural languages
Functional Paradigm

- Computation is expressed as **functions** of data

- In *Pure* Functional Programming there are
  - No explicit assignment or “variables”
  - No explicit control structures such as IF, FOR or WHILE

- Functional languages are Turing equivalent to procedural languages

- The key to understanding a functional program is to ask “*What value does it return?*.”
Functional Sorting

We could express a sort of set $T$ functionally:

$$S = \text{mergeSort}(T) \{$$
Functional Sorting

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$$S = \text{mergeSort}(T) \{ (\text{empty}(T) \| \text{singleton}(T)) \ ? \ : \ , \}$$

- Find value of condition
Functional Sorting

► We could express a sort of set $T$ functionally:

$$ S = \text{mergeSort}(T) \{ \begin{array}{l} (\text{empty}(T) \text{ || } \text{singleton}(T)) \quad ? \\ T \quad : \quad , \end{array} \} $$

► Find value of condition

► Empty and single-item lists are already sorted
Functional Sorting

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  $$S = \text{mergeSort}(T) \{ \begin{array}{l}
  (\text{empty}(T) || \text{singleton}(T)) \ ? \\
  T : \\
  \text{firsthalf}(T), \\
  \text{secondhalf}(T)
  \end{array} \}$$

- Find value of condition
- Empty and single-item lists are already sorted
- Break up problem and solve pieces
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  - Partition list 1 into 2 sublists
Functional Sorting

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T : \\
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- Find value of condition

- Empty and single-item lists are already sorted

- Break up problem and solve pieces
  - Partition list 1 into 2 sublists
  - Sort each sublist
Functional Sorting

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- Find value of condition

- Empty and single-item lists are already sorted

- Break up problem and solve pieces
  - Partition list 1 into 2 sublists
  - Sort each sublist
  - Merge sorted sublists
Comments on Functional Paradigm I

- New data is computed from old data instead of modifying the old data
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- Facilitated by dynamic allocation and garbage collection
Comments on Functional Paradigm I

▶ New data is computed from old data instead of modifying the old data

▶ Facilitated by dynamic allocation and garbage collection

▶ Dominant computational metaphors are
  ▶ composition
  ▶ recursion
    ▶ breaking a problem down into simpler but similar problems
    ▶ solving them and then
    ▶ putting the results back together again
Comments on Functional Paradigm II

- Also known as "Applicative" programming
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- Use recursive structure (e.g. lists and trees)
  - Easy to build from parts created recursively
Comments on Functional Paradigm II

▶ Also known as "Applicative" programming

▶ Use recursive structure (e.g. lists and trees)
  ▶ Easy to build from parts created recursively

▶ Sisal uses compiler tricks and clever datastructures to avoid without copying data repeatedly
Examples of Functional Languages

How many do you know?

- LISP & Scheme (First of its class)
- used in AI
- still used in prototyping and symbolic processing
- can treat programs as data and data as programs
- used as a configuration and scripting language
- CAD/CAM applications and EMA CS customizable editor
- ML (non-pure functional language), Haskell (pure)
- Miranda (rst functional language intended for commercial applications)
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Generic Functions

- Generic functions are to functional languages as class polymorphism is to object-oriented languages.
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- Functions are dispatched based on the types of the arguments supplied to the function.
Generic Functions

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- Functions are dispatched based on the types of the arguments supplied to the function.

- `size-of(list)`, `size-of(vector)` and `size-of(hash-table)` call different underlying implementations.
Sort with Generic Functions

- The sort "function" can have different implementations for different types of arguments
  - Integers and reals can be sorted using the ">" partial order relation
  - Vectors could be sorted using their length |V| with a partial order relation
  - Nodes in a graph could be sorted by their degrees

- Again, user doesn’t need to understand the details
Languages with Generic Functions

- Common LISP implements generic programming
Languages with Generic Functions

- C++ implement generic programming through the Standard Template Library (STL)
- Common LISP implements generic programming
Declarative Paradigm

- Emphasis is on what the computation should achieve - not how
Declarative Paradigm

- Emphasis is on *what* the computation should achieve - not how

1. Enter *facts* and *rules* (a.k.a. axioms) to describe a situation or domain.
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3. Language searches for a proof of the query
   - The language can return true, false or unproveable
   - The language attempts to find assignments to variables in order to make the statement true
Example Facts, Rules and Queries

▶ Facts:

MATH322 is Boring.
Clyde is an elephant.
Example Facts, Rules and Queries

- **Facts:**
  
  MATH322 is Boring.
  Clyde is an elephant.

- **Rules:**
  
  X is boring $\Rightarrow$ X makes me sleepy
  X is-an elephant $\Rightarrow$ X is heavy
Example Facts, Rules and Queries

► Facts:

MATH322 is Boring.
Clyde is an elephant.

► Rules:

X is boring \Rightarrow X makes me sleepy
X is-an elephant \Rightarrow X is heavy

► Queries:

MATH322 is boring \rightarrow true
CMPUT325 is boring \rightarrow unproveable given what you know
There exists an X which is boring
\rightarrow is true for X = MATH322
Declarative Sort

Expressing that $S$ is a sort of set $T$ declaratively:

$$T \text{ is-a-sort-of } S \iff T \text{ contains each element of } S$$
and for each element $i$ of $T$, $T(i) > T(i+1)$
Declarative Sort

- Expressing that \( S \) is a sort of set \( T \) declaratively:

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T \text{ is-a-sort-of } S \\
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- Given a set of elements \( T \), formulate a statement to prove

\[
\exists S. S \text{ is-a-sort-of } T
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- Let language search for an $S$ that makes statement true
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  \[ \exists S. S \text{ is a sort of } T \]

- Let language search for an $S$ that makes statement true

- The set of possible $S$’s that make the above query true are exactly the legal ways to sort $T$. 
Comments on Declarative Paradigm I

- Dominant computational metaphors are
  - axiomatization (writing down rules and facts)
  - inference

Sometimes: Easier to say what we want than how to do it

But, the computation may be inefficient without constraints on implementation

Generic knowledge can sometimes be reused in powerful ways

The concept of an ordered set could be used in a sort program, but also reused in reasoning about time intervals or geometric relationships or neighbours.
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- Declarative knowledge is relational - not functional or causal
  - The statement $S$ is a sort of $T$ relates $S$ and $T$
  - We can find a sort $S$ given a set $T$
  - But, we can also find all sets $T$ that can be sorted to produce $S$
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- Unlike functions which always calculate a result from an argument, we say that declarative knowledge can be used in forward or backward directions
Examples of Declarative Languages

- PROLOG (widely used in AI especially in Europe)
  - Did you know that there are object-oriented extensions to Prolog?
  - Implements a limited form of First Order Logic that can be proved efficiently through "resolution"

- SQL (the preeminent language for describing database queries)
Constraint-Based Paradigm

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- Language attempts to find a satisfying assignment of variables
Constraint-Based Sorting

- We start with a list $T = (i_1, \ldots, i_n)$ and desire a sorted list $S = (s_1, \ldots, s_n)$
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- Set up two constraints on each variable $s_i$
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- Any satisfying assignment of values to variables corresponds to a sort of $T$
Comments on Constraint Paradigm

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- Clever techniques can sometimes be used to avoid computing all constraints.
- Can do optimization with constraints.
  - Common techniques: Linear and Quadratic programs.
Probabilistic Inference Paradigm

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- Logics represent uncertainty by disjunction: $a \lor b$, existential quantification: $\exists x.\text{tall}(x)$ and negation: $\neg X = fred$
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- Probabilistic models represent uncertainty with numbers: $\Pr(a) = \frac{1}{4}$, $\Pr(\neg a) = \frac{3}{4}$
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- Can specify conditional probabilities
  - $\Pr(\text{sparrow}(a\text{Bird})) = 0.80$ - prior probability $\equiv$ fact
  - $\Pr(\text{flies}(B)|\text{penguin}(B)) = 0$ - conditional probability $\equiv$ rule
  - $\Pr(\text{flies}(B)|\text{sparrow}(B)) = 0.9$
Probabilistic Inference Paradigm

- An extension of declarative programming

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  - $\Pr(\text{flies}(B)|\text{sparrow}(B)) = 0.9$

- Language assigns probabilities to statements:
  $\Pr(\text{flies(\text{aBird})}) \rightarrow 0.72$
Comments of Probabilistic Paradigm

- **Dominant Constructs**
  - Definition of prior and conditional probabilities
  - Probabilistic inference
Comments of Probabilistic Paradigm

- **Dominant Constructs**
  - Definition of prior and conditional probabilities
  - Probabilistic inference

- **Result is a distribution over possible answers**
  - $\text{Pr}(\text{flies(aBird)}) \rightarrow 0.72$ and $\text{Pr}(\neg\text{flies(aBird)}) \rightarrow 0.28$
Comments of Probabilistic Paradigm

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  - Definition of prior and conditional probabilities
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- Choose actions with highest expected values
Concurrent Paradigm

- Many different processes
  All running “at same time”
  Each executing a different instruction
Concurrent Paradigm

- Many different processes
  All running “at same time”
  Each executing a different instruction

- Issues:
  - Allocation of resources
  - Partitioning of computations
  - Communication overhead
  - Synchronization
  - Deadlock, Starvation, …
Examples of Concurrency

- Multiplying two $n \times n$ matrices $R = AB$
  - Need to compute $n^3$ independent values:
    $$R_{ij} = \sum_k A(i, k) \times B(k, j)$$
  - Parallelize this to speed up computation
Concurrent Sorting

- The best algorithm for concurrent sorting depends on the architecture of the parallel platform
- For grid processors, we might use a "snake sort"
Paradigm Summary

- Procedural
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  - Tell computer to alter data
  - a.k.a. "Imperative"
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  ▶ Tell computer to alter data
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  - Encapsulation provides control over alteration

- **Functional**
  - Result is a function of data
  - Data never altered
Paradigm Summary

▶ Declarative
Paradigm Summary

- **Declarative**
  - Define properties of solution
  - Theorem prover finds satisfying answers
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- **Contraints**
  - Simplification of logical declarative paradigm
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Paradigm Summary

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  ▶ Define properties of solution
  ▶ Theorem prover finds satisfying answers

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▶ Concurrent
  ▶ Simultaneous execution instructions
  ▶ Requires locking, synchronization, etc.