Abstract Data Types (I)
(and Object-Oriented Programming)

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How many horses can you distinguish?





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Mind's Limit Found: 4 Things at Once

By Clara Moskowitz | April 27, 2008 08:00pm ET

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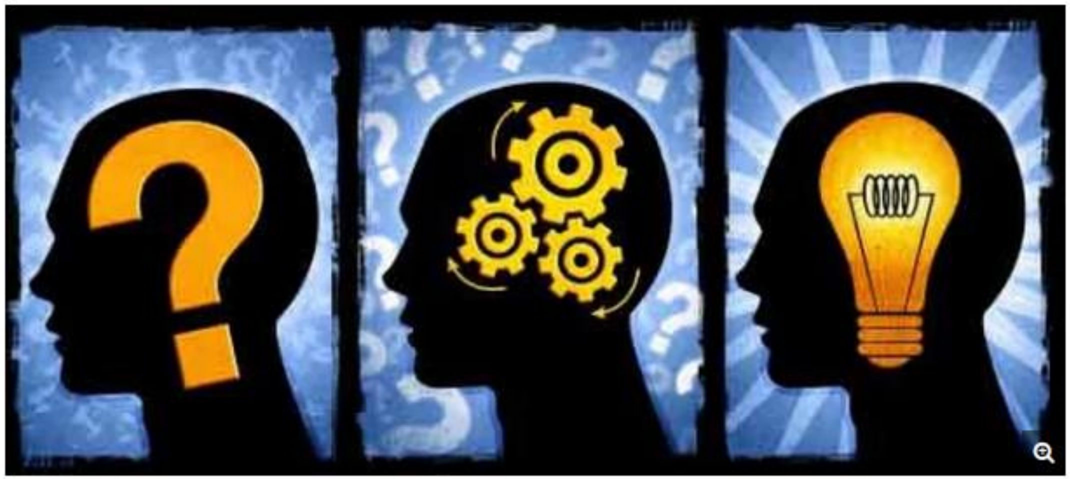


I forget how I wanted to begin this story. That's probably because my mind, just like everyone else's, can only remember a few things at a time. Researchers have often debated the maximum amount of items we can store in our conscious mind, in what's called our working memory, and a new study puts the limit at three or four.

Working memory is a more active version of short-term memory, which refers to the temporary storage of information. Working memory relates to the information we can pay attention to and manipulate.

Two examples

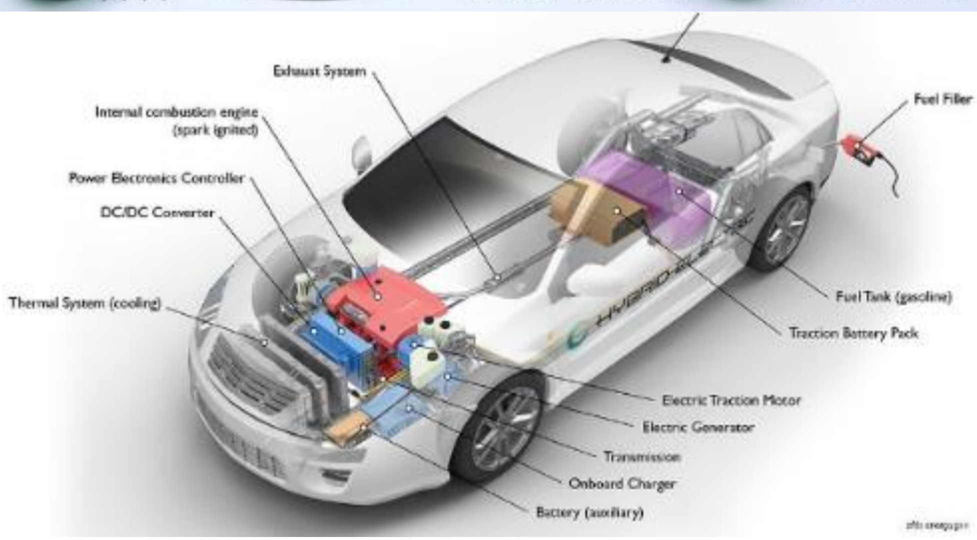
```
// Main loop of binary search
while (left <= right) {
    int i = (left + right)/2;
    if (x < A[i]) right = i – 1;
    else if (x > A[i]) left = i + 1;
    else return i;
}
```

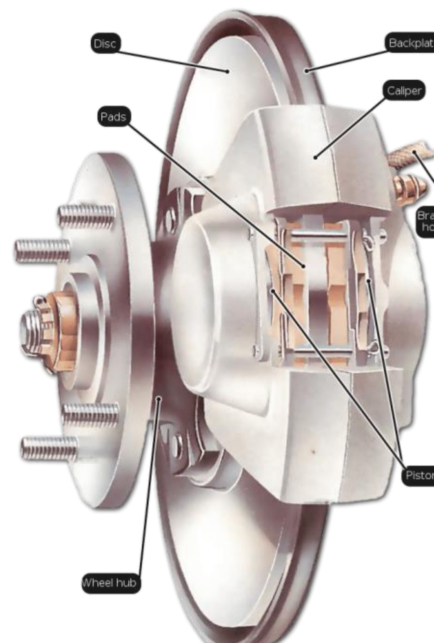
Variables used (5):
A, x, left, right, i
(only 3 modified)

```
// Main loop of insertion sort
for (int i = 1; i < A.size(); ++i) {
    int x = A[i];
    int j = i;
    while (j > 0 and A[j - 1] > x) {
       A[j] = A[j - 1];
       --j;
    }
    A[j] = x;
}
```

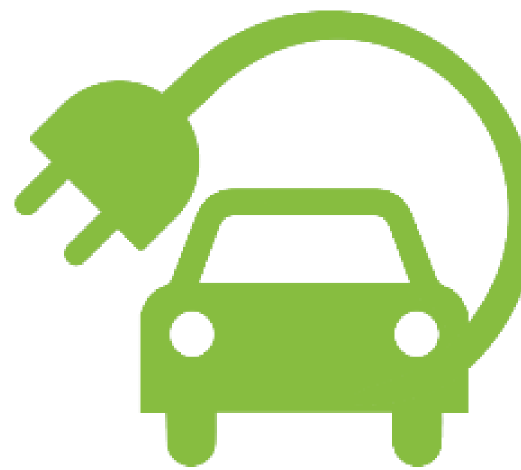
Variables used (4):
A, x, i, j

Hiding details: abstractions

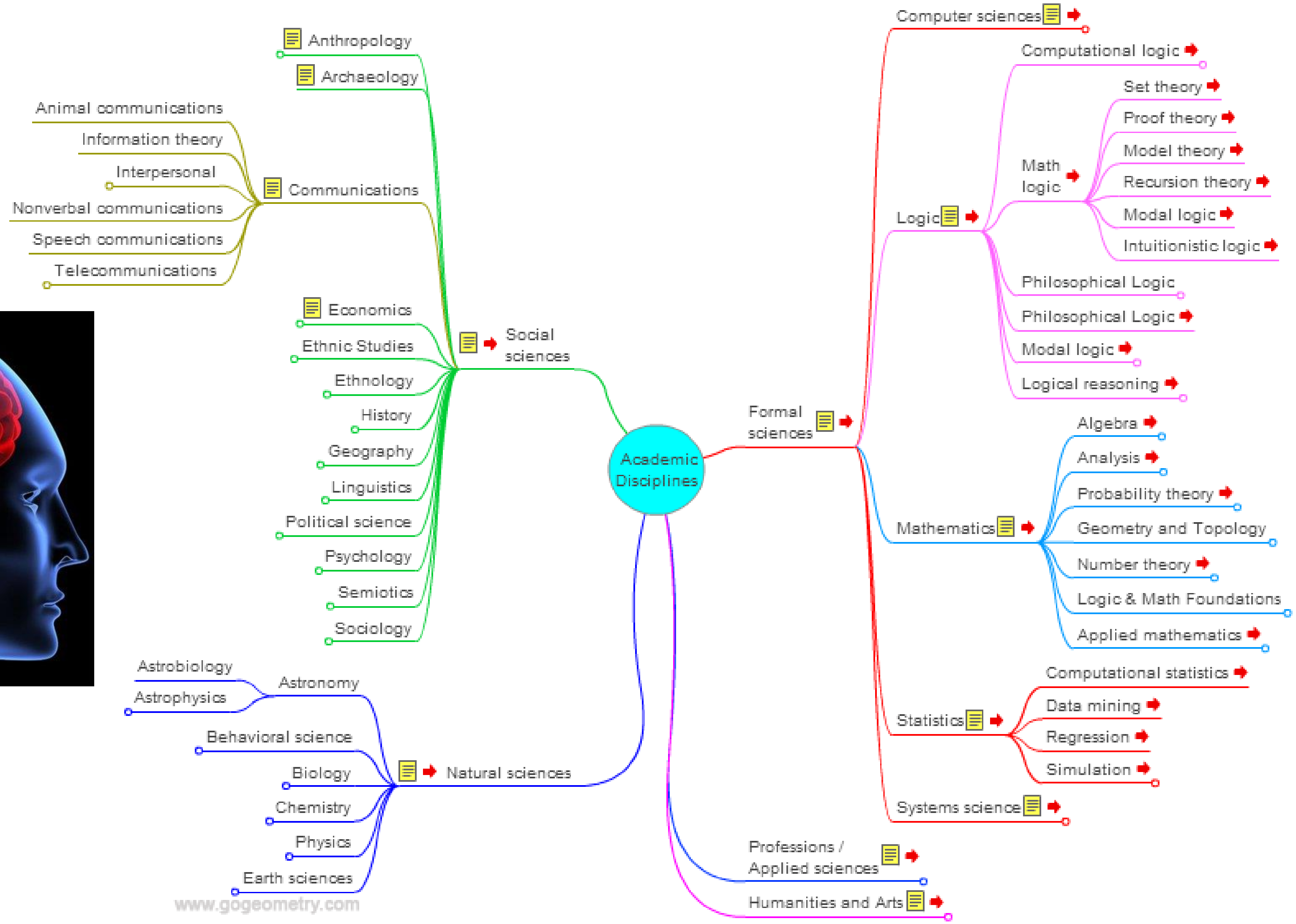




Different types of abstractions



Concept maps are hierarchical: why?



Each level has few items

The computer systems stack

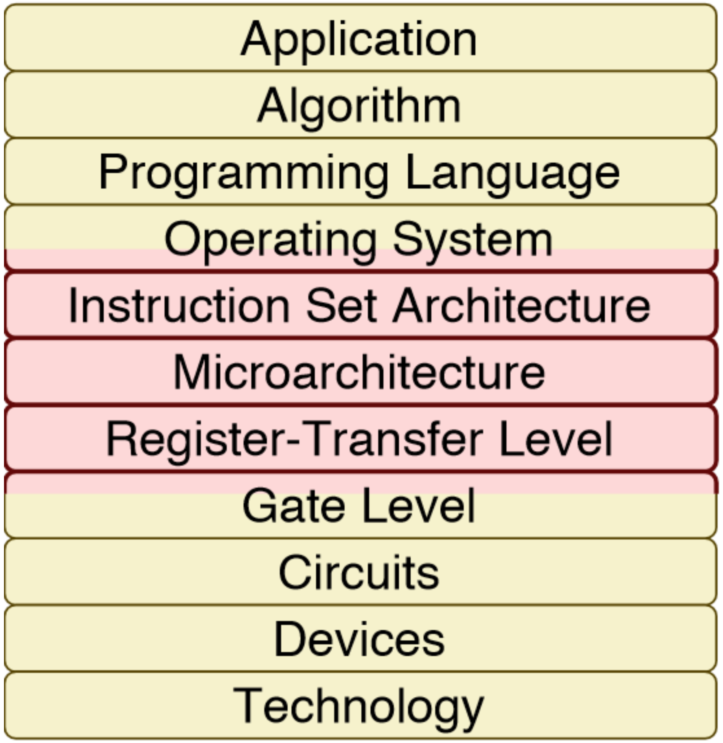


Image Credit: Christopher Batten, Cornell University

The computer systems stack

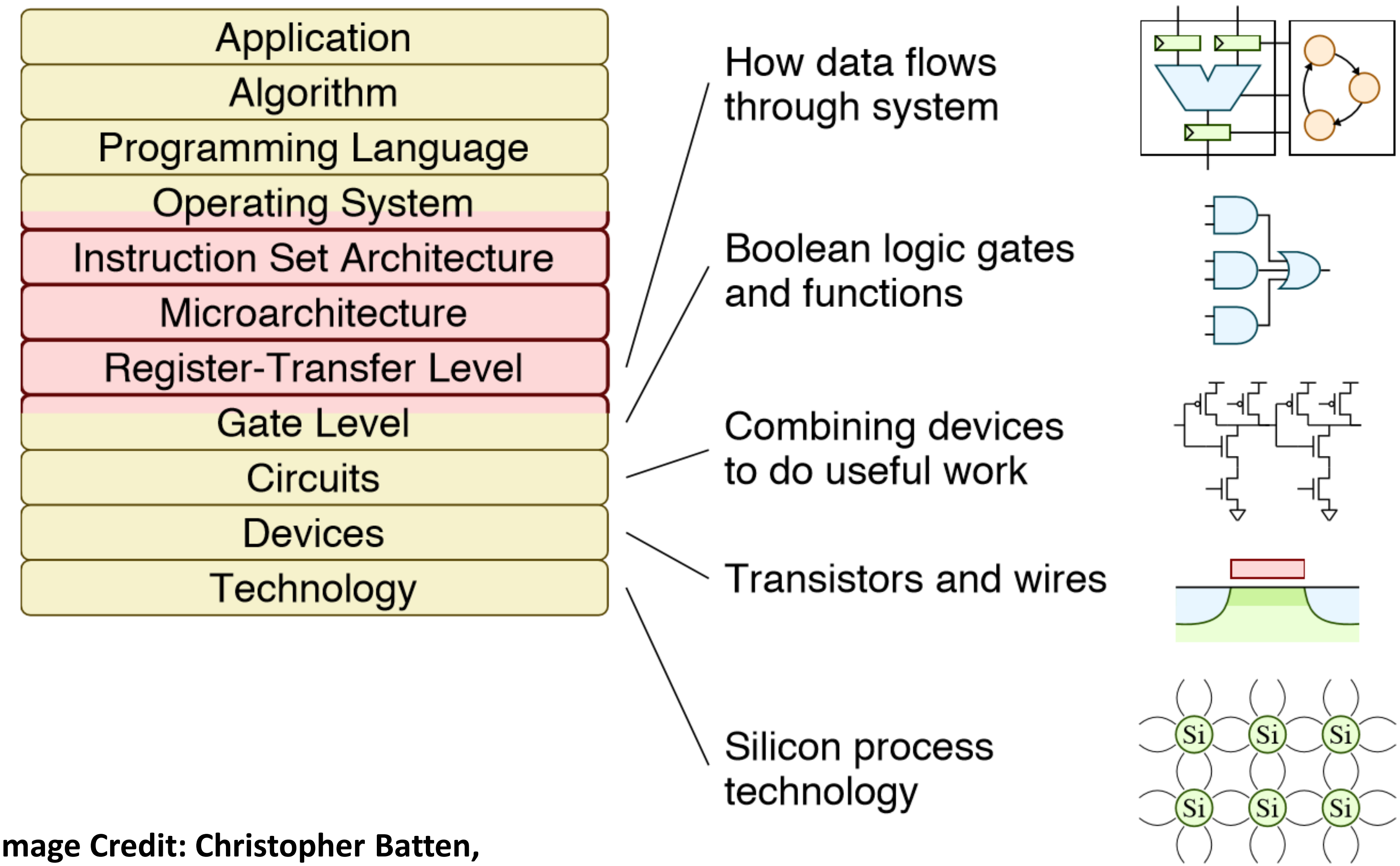


Image Credit: Christopher Batten, Cornell University

The computer systems stack

- Application
- Algorithm
- Programming Language
- Operating System
- Instruction Set Architecture
- Microarchitecture
- Register-Transfer Level
- Gate Level
- Circuits
- Devices
- Technology

Mac OS X, Windows, Linux

Handles low-level hardware management

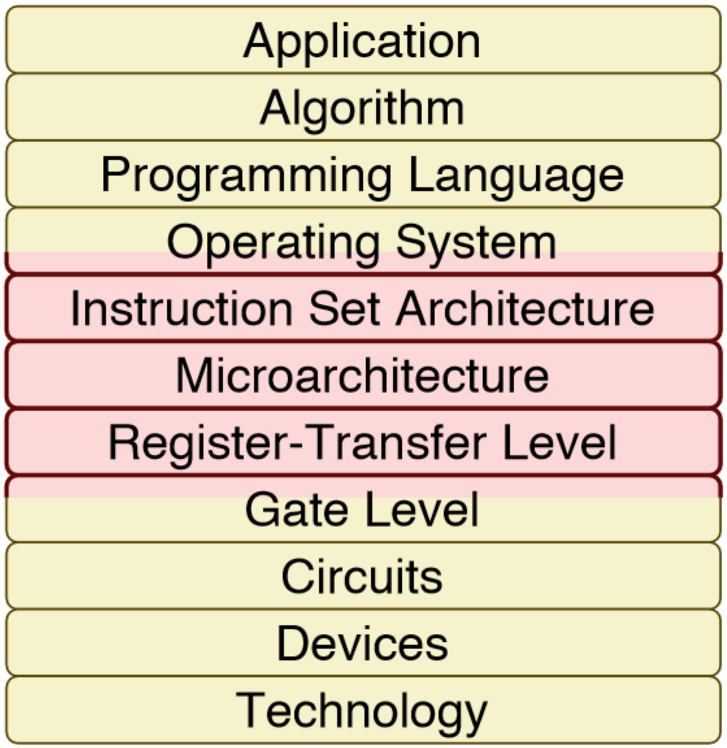
MIPS32 Instruction Set

Instructions that machine executes

```
blez  $a2, done
move  $a7, $zero
li    $t4, 99
move  $a4, $a1
move  $v1, $zero
li    $a3, 99
lw    $a5, 0($a4)
addiu $a4, $a4, 4
slt   $a6, $a5, $a3
movn  $v0, $v1, $a6
addiu $v1, $v1, 1
movn  $a3, $a5, $a6
```

Image Credit: Christopher Batten, Cornell University

The computer systems stack



Sort an array of numbers

2,6,3,8,4,5 -> 2,3,4,5,6,8

Insertion sort algorithm

1. Find minimum number in input array
2. Move minimum number into output array
3. Repeat steps 1 and 2 until finished

C implementation of insertion sort

```
void isort( int b[], int a[], int n ) {
  for ( int idx, k = 0; k < n; k++ ) {
    int min = 100;
    for ( int i = 0; i < n; i++ ) {
      if ( a[i] < min ) {
        min = a[i];
        idx = i;
      }
    }
    b[k]   = min;
    a[idx] = 100;
  }
}
```

Image Credit: Christopher Batten, Cornell University

Our challenge

- We need to design large systems and reason about complex algorithms.
- Our working memory can only manipulate 4 things at once.
- We need to interact with computers using programming languages.
- Solution: abstraction
  - Abstract reasoning.
  - Programming languages that support abstraction.
- We already use a certain level of abstraction: functions. But it is not sufficient. We need much more.

Data types

- Programming languages have a set of primitive data types (e.g., int, bool, double, char, …).

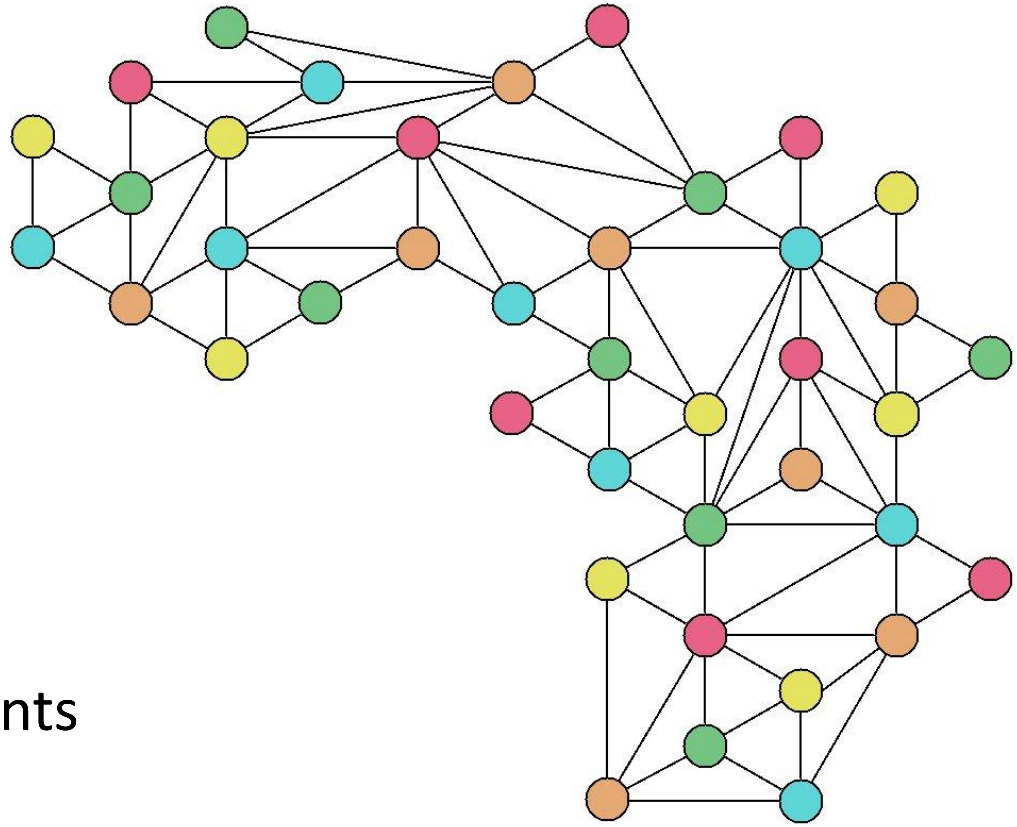
- Each data type has a set of associated operations:
  - We can add two integers.
  - We can concatenate two strings.
  - We can divide two doubles.
  - But we cannot divide two strings!

- Programmers can add new operations to the primitive data types:
  - gcd(a,b), match(string1, string2), …

- The programming languages provide primitives to group data items and create structured collections of data:
  - C++: array, struct.
  - python: list, tuple, dictionary.

Abstract Data Types (ADTs)

A set of objects and a set of operations to manipulate them



Operations:

- Number of vertices
- Number of edges
- Shortest path
- Connected components

Data type: Graph

Abstract Data Types (ADTs)

A set of objects and a set of operations to manipulate them:

$$\boldsymbol{P(x) = x^3 - 4x^2 + 5}$$

Data type: Polynomial

<u>Operations:</u>

- $P + Q$
- $P \times Q$
- P/Q
- $\mathrm{gcd}(P, Q)$
- $P(x)$
- $\mathrm{degree}(P)$

Abstract Data Types (ADTs)

- Separate the notions of specification and implementation:
  - Specification: “what does an operation do?”
  - Implementation: “how is it done?”

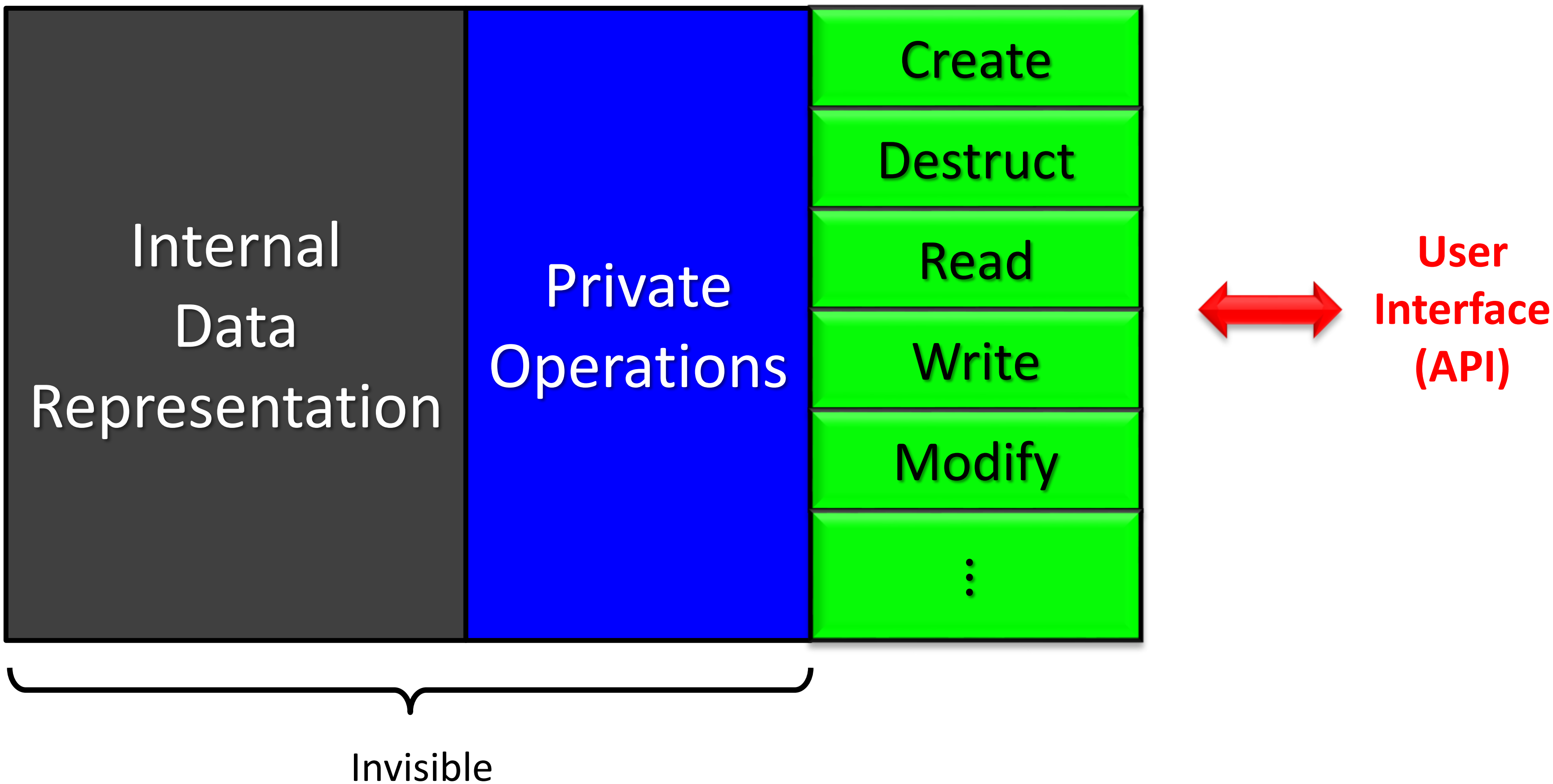
- Benefits:
  - Simplicity: code is easier to understand
  - Encapsulation: details are hidden
  - Modularity: an ADT can be changed without modifying the programs that use it
  - Reuse: it can be used by other programs

Abstract Data Types (ADTs)

- An ADT has two parts:
  - Public or external: abstract view of the data and operations (methods) that the user can use.
  - Private or internal: the actual implementation of the data structures and operations.

- Operations:
  - Creation/Destruction
  - Access
  - Modification

Abstract Data Types (ADTs)

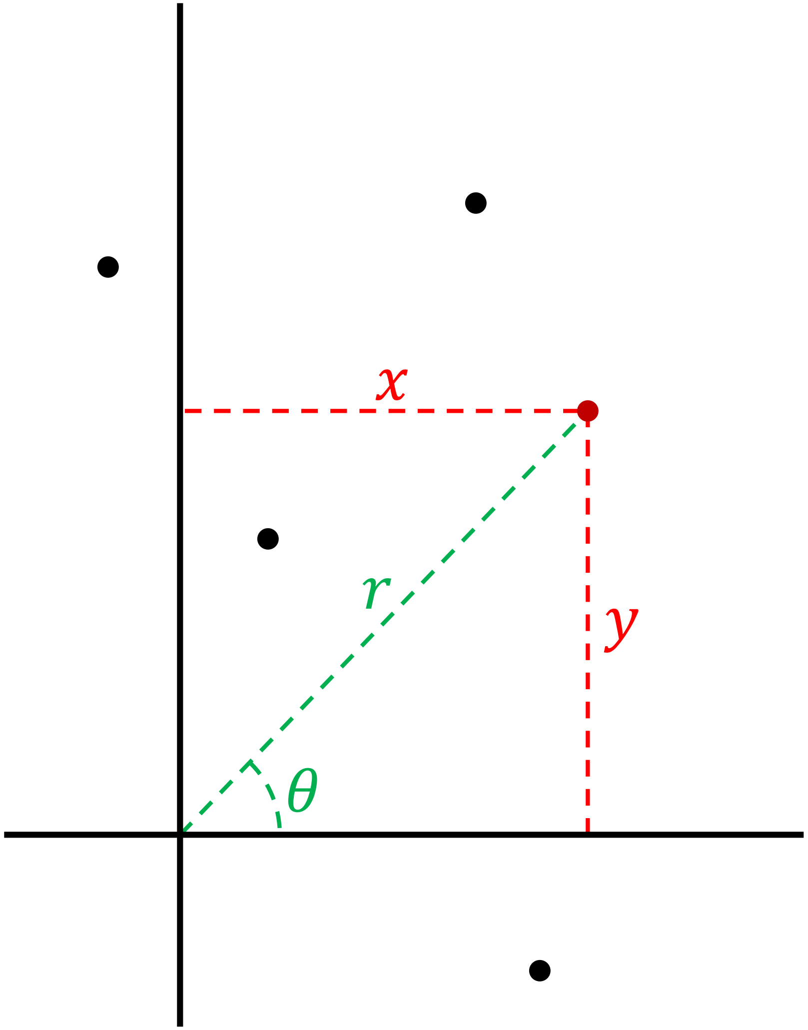


API: Application Programming Interface

Example: a Point

- A point can be represented by two coordinates (x,y).

- Several operations can be envisioned:
  - Get the x and y coordinates.
  - Calculate distance between two points.
  - Calculate polar coordinates.
  - Move the point by $(\Delta x, \Delta y)$.



Example: a Point

```
// Things that we can do with points

Point p1(5.0, -3.2); // Create a point (a variable)
Point p2(2.8, 0);    // Create another point

// We now calculate the distance between p1 and p2
double dist12 = p1.distance(p2);

// Distance to the origin
double r = p1.distance();

// Create another point by adding coordinates
Point p3 = p1 + p2;

// We get the coordinates of the new point
double x = p3.getX();  // x = 7.8
double y = p3.getY();  // y = -3.2
```

ADTs and Object-Oriented Programming

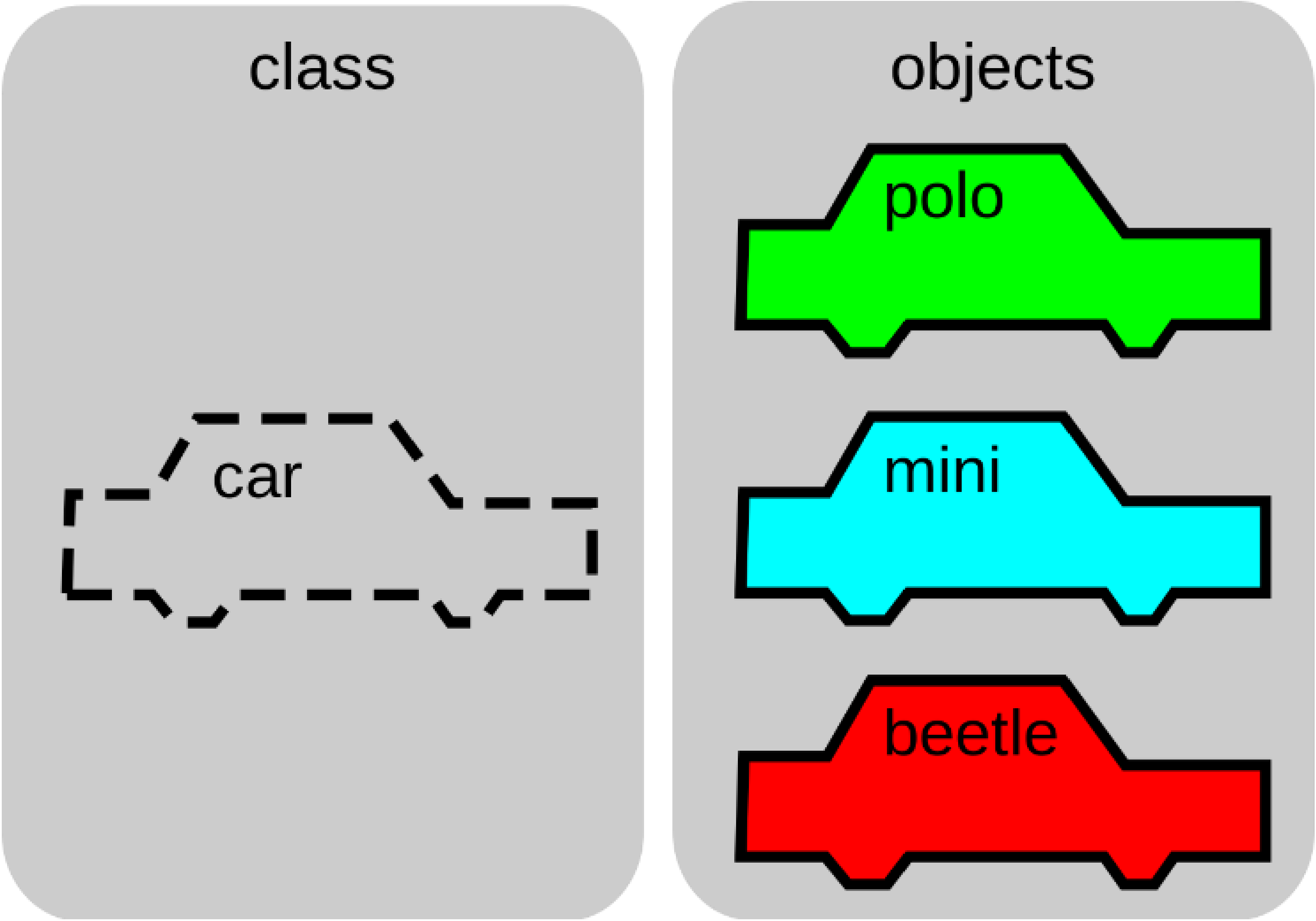
- OOP is a programming paradigm: a program is a set of objects that interact with each other.

- An object has:
  - fields (or attributes) that contain data
  - functions (or methods) that contain code

- Objects (variables) are instances of classes (types).
  A class is a template for all objects of a certain type.

- In OOP, a class is the natural way of implementing an ADT.

Classes and Objects



Let us design the new type for Point

```
// The declaration of the class Point
class Point {

public:
  // Constructor
  Point(double x_coord, double y_coord);

  // Constructor for (0,0)
  Point();

  // Gets the x coordinate
  double getX() const;

  // Gets the y coordinate
  double getY() const;

  // Returns the distance to point p
  double distance(const Point& p) const;

  // Returns the distance to the origin
  double distance() const;

  // Returns the angle of the polar coordinate
  double angle() const;

  // Creates a new point by adding the coordinates of two points
  Point operator + (const Point& p) const;

private:
  double x, y;  // Coordinates of the point

};
```

Implementation of the class Point

```
// The constructor: different implementations
Point::Point(double x_coord, double y_coord) {
  x = x_coord; y = y_coord;
}

// or also
Point::Point(double x_coord, double y_coord) :
  x(x_coord), y(y_coord) {}

// or also
Point::Point(double x, double y) : x(x), y(y) {}
```

All of them are equivalent, but only one of them should be chosen. We can have different constructors with different *signatures*.

```
// The other constructor
Point::Point() : x(0), y(0) {}
```

Implementation of the class Point

```
double Point::getX() const {
  return x;
}

double Point::getY() const {
  return y;
}


double Point::distance(const Point& p) const {
  double dx = getX() – p.getX(); // Better getX() than x
  double dy = getY() – p.getY();
  return sqrt(dx*dx + dy*dy);
}

double Point::distance() const {
  return sqrt(getX()*getX() + getY()*getY());
}
```

Note: compilers are smart. Small functions are expanded inline.

Implementation of the class Point

```
double Point::angle() const {
  if (getX() == 0 and getY() == 0) return 0;
  return atan(getY()/getX());
}

Point Point::operator + (const Point& p) const {
  return Point(getX() + p.getX(), getY() + p.getY());
}
```

operator overloading

```
p1 + p2
```

“this” object

parameter of operator +

File organization: one file

Point.hh

```
#ifndef __POINT_H__
#define __POINT_H__

class Point {

public:
  // Constructor
  Point(double x, double y) : x(x), y(y)
  {}

  // Gets the x coordinate
  double getX() const {
      return x;
  }

        ⋮

private:
  double x, y;  // Coordinates of the point

};

#endif // __POINT_H__
```

Only one header file (.hh) that contains the specification and the implementation.

<u>Advantages:</u>

- Easy distribution.
- Useful to implement templates.

<u>Disadvantages:</u>

- More compile effort.
- The implementation is revealed.

File organization: two files

Point.hh

```
#pragma once

class Point {

public:
  // Constructor
  Point(double x, double y);

  // Gets the x coordinate
  double getX() const;

        ⋮

private:
  double x, y;  // Coordinates of the point

};
```

Point.cc

```
#include "Point.hh"

Point::Point(double x, double) : x(x), y(y)
{}


double Point::getX() const {
    return x;
}

        ⋮
```

A header file (.hh) containing the specification and a C++ file (.cc) containing the implementation.

Advantages:

- Less compile effort.
- Hidden implementation.

Disadvantages:

- Need to distribute a library.
- Data representation still visible.

Conclusions

- The human brain has limitations: 4 things at once.
- Modularity and abstraction are for designing large maintainable systems.