Concepts of Object-Oriented Programming

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Programming Methodology Group

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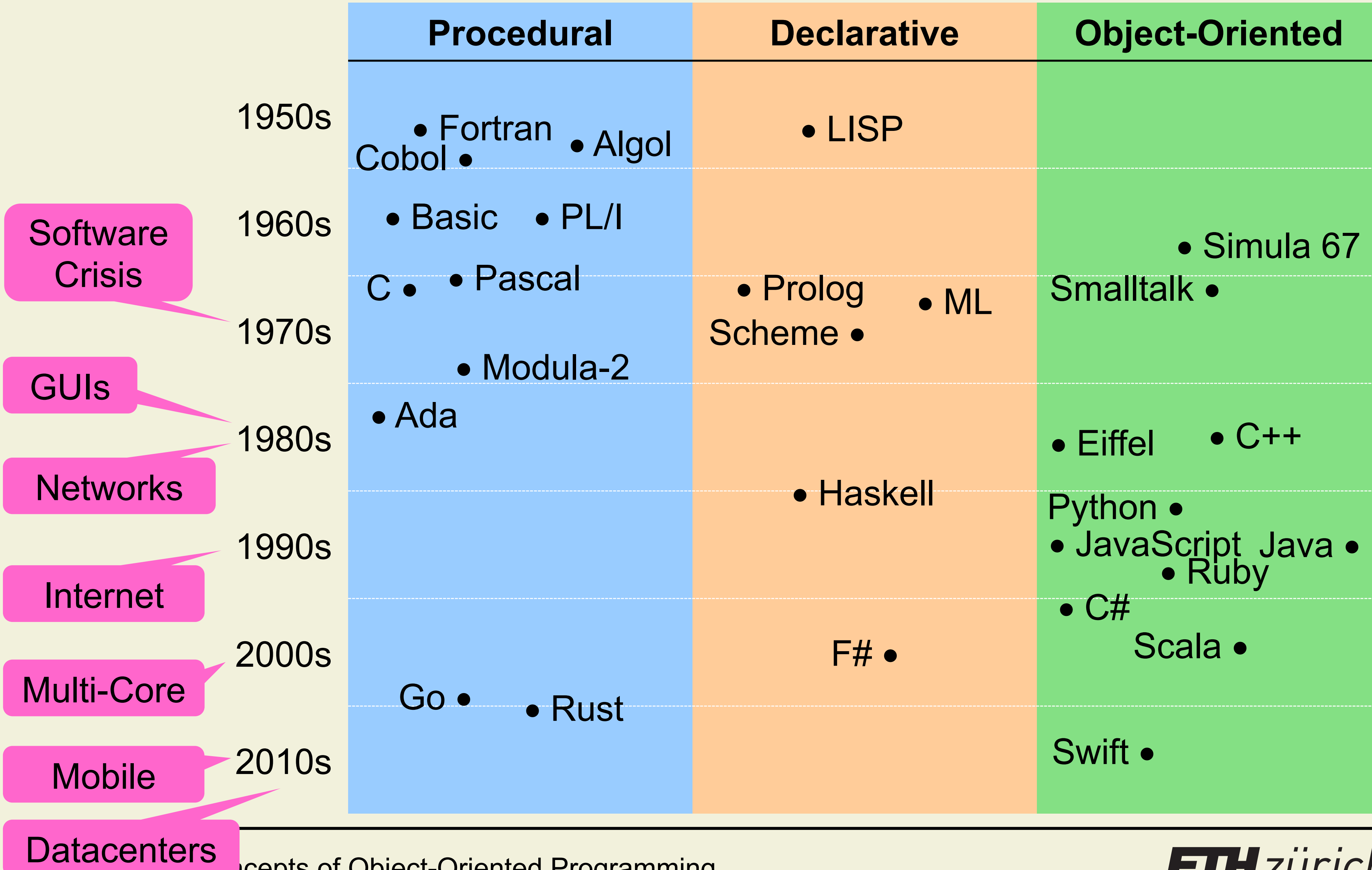
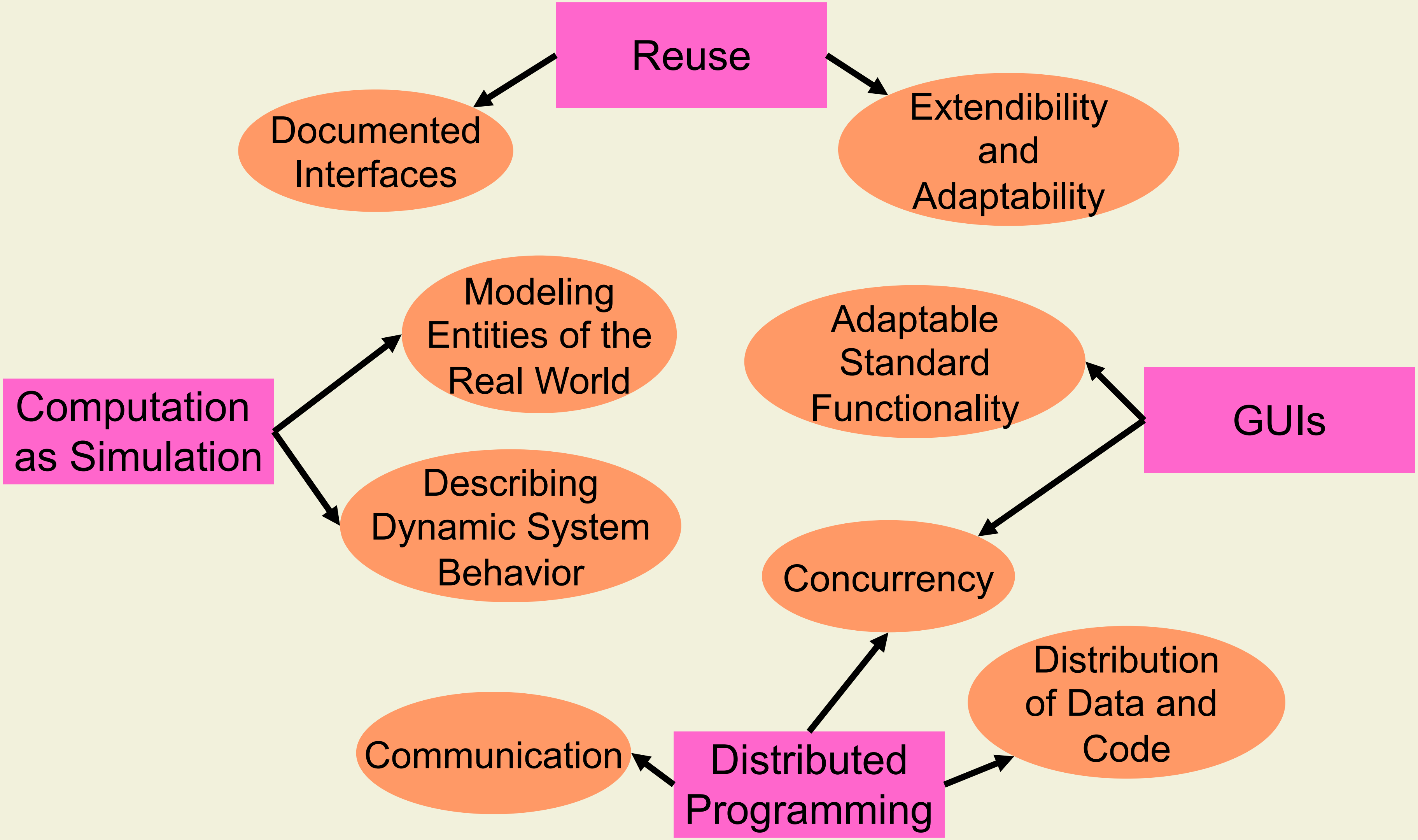
ETH zürich

History of Programming Languages



1. Introduction

Requirements Motivating OOP



Example: Reusing Procedural Programs

- Scenario: University Administration System
  - Models students and professors
  - Stores one record for each student and each professor in a repository
  - Procedure printAll prints all records in the repository

An Implementation in C

```
typedef struct {
  char *name;
  char *room;
  char *institute;
} Professor;

typedef struct {
  char *name;
  int  regNum;
} Student;
```

```
void printStudent( Student *s )
  { … }

void printProf( Professor *p )
  { … }
```

An Implementation in C (cont'd)

```
typedef struct {
  enum { STU,PROF } kind;
  union  {
    Student *s;
    Professor *p;
  } u;
} Person;

typedef Person **List;
```

```
void printAll( List l ) {
  int i;
  for ( i=0; l[ i ] != NULL; i++ )
    switch ( l[ i ] -> kind ) {
    case STU:
      printStudent( l[ i ] -> u.s );
      break;
    case PROF:
      printProf( l[ i ] -> u.p );
      break;
    }
}
```

Extending and Adapting the Program

- Scenario: University Administration System
  - Models students and professors
  - Stores one record for each student and each professor in a repository
  - Procedure printAll prints all records in the repository
- Extension: Add assistants to system
  - Add record and print function for assistants
  - Reuse old code for repository and printing

Step 1: Add Record and Print Function

```
typedef struct {
  char *name;
  char *room;
  char *institute;
} Professor;

typedef struct {
  char *name;
  int   regNum;
} Student;

typedef struct {
  char *name;
  char  PhD_student;  /* ‘y‘, ‘n‘ */
} Assistant;
```

```
void printStudent( Student *s )
  { … }

void printProf( Professor *p )
  { … }

void printAssi( Assistant *a )
  { … }
```

Step 2: Reuse Code for Repository

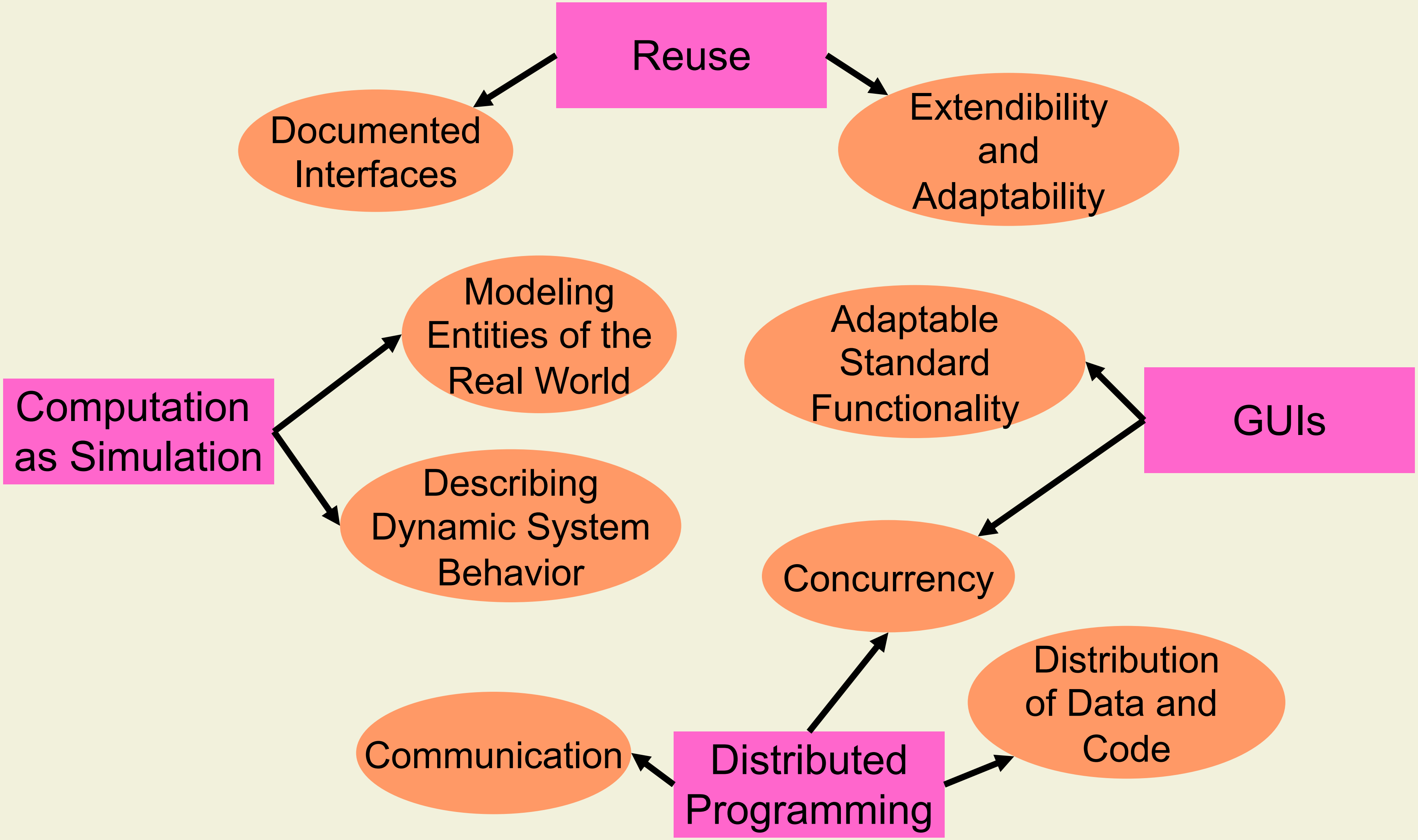
```
typedef struct {
  enum { STU,PROF,ASSI } kind;
  union  {
    Student *s;
    Professor *p;
    Assistant *a;
  } u;
} Person;

typedef Person **List;
```

```
void printAll( List l ) {
  int i;
  for ( i=0; l[ i ] != NULL; i++ )
    switch ( l[ i ] -> kind ) {
    case STU:
      printStudent( l[ i ] -> u.s );
      break;
    case PROF:
      printProf( l[ i ] -> u.p );
      break;
    case ASSI:
      printAssi( l[ i ] -> u.a );
      break;
    }
}
```

Reuse in Procedural Languages

- No explicit language support for extension and adaptation
- Adaptation usually requires modification of reused code
- Copy-and-paste reuse
    - Code duplication
    - Difficult to maintain
    - Error-prone

Requirements Motivating OOP



1. Introduction

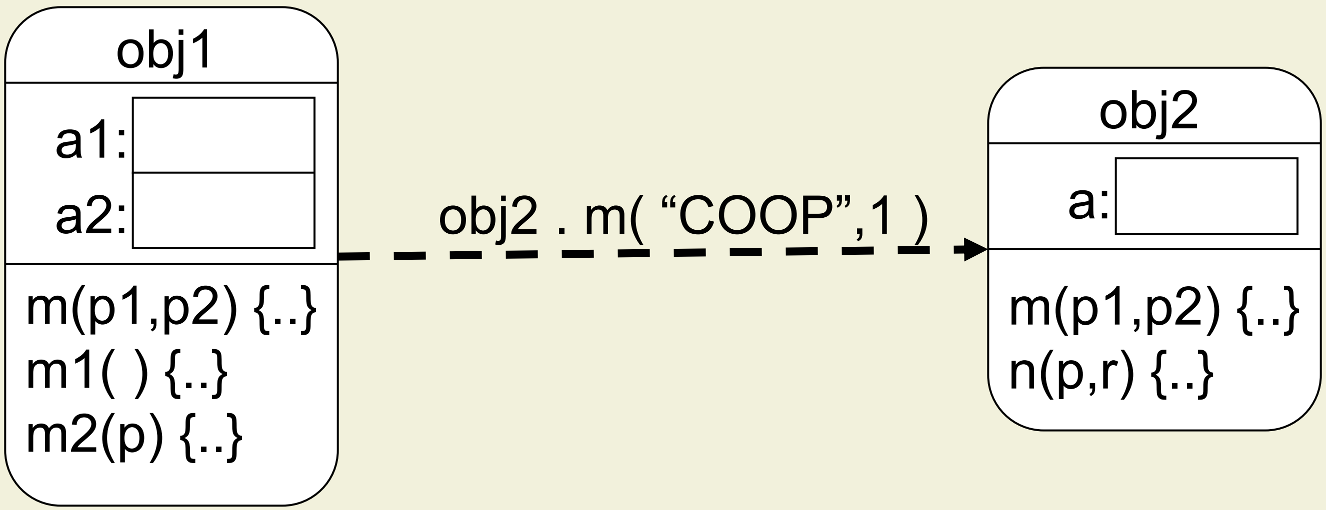
Object Model: The Philosophy

“The basic philosophy underlying object-oriented programming is to make the programs as far as possible reflect that part of the reality they are going to treat. It is then often easier to understand and to get an overview of what is described in programs. The reason is that human beings from the outset are used to and trained in the perception of what is going on in the real world. The closer it is possible to use this way of thinking in programming, the easier it is to write and understand programs.“

[Object-oriented Programming in the BETA Programming Language]

Core Concept 1: The Object Model

- A software system is a set of cooperating objects
- Objects have state and processing ability
- Objects exchange messages



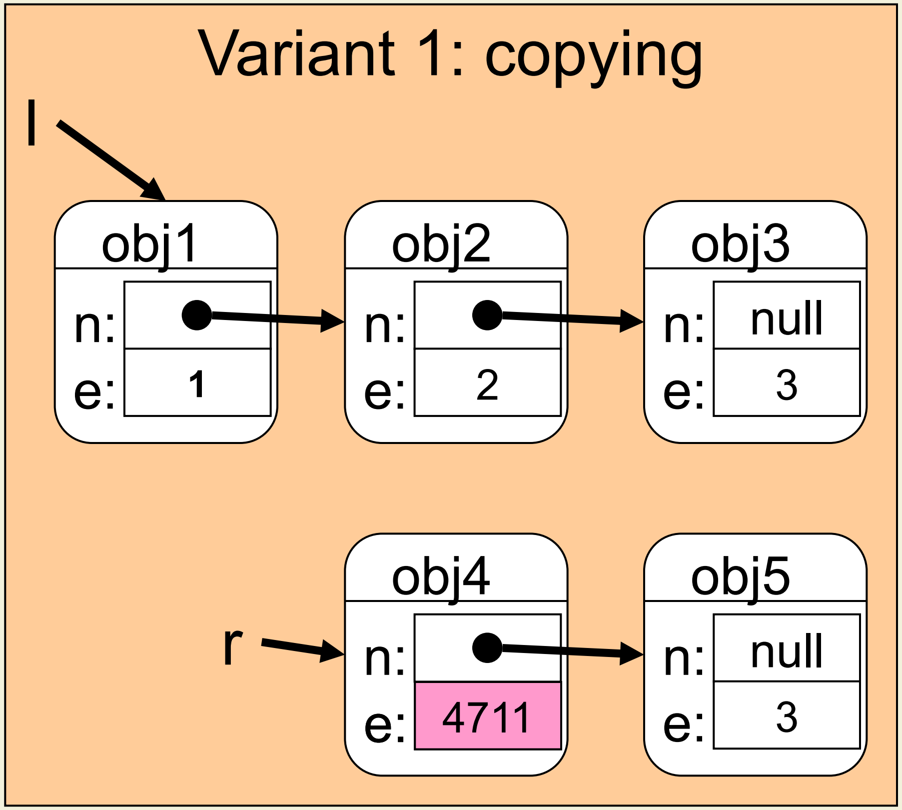
Characteristics of Objects

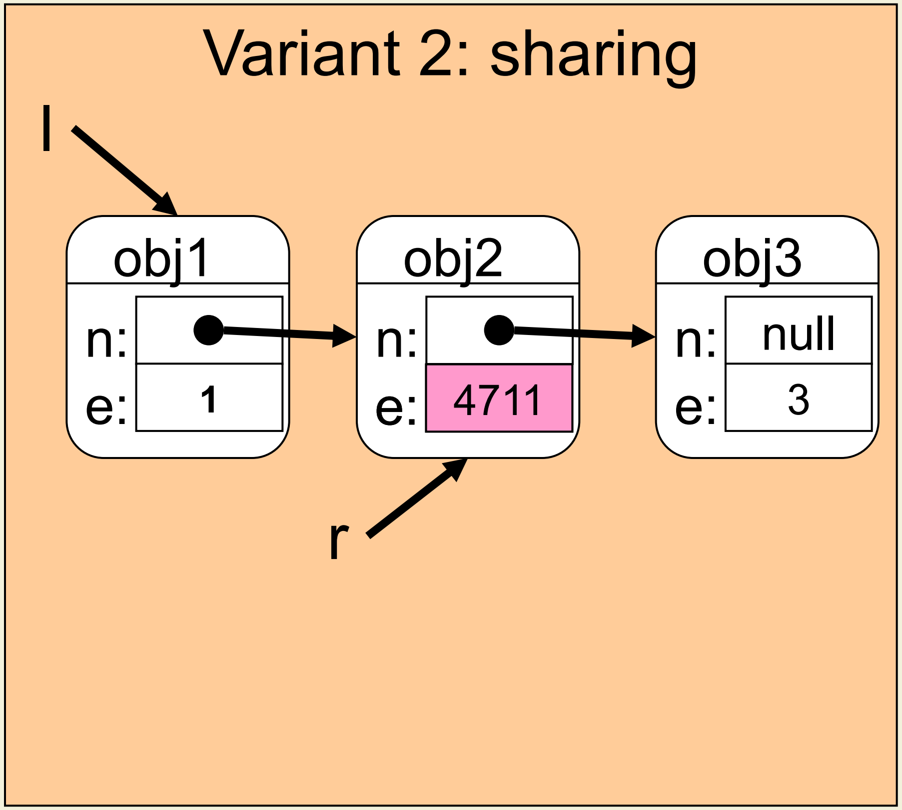
- Objects have
  - State
  - Identity
  - Lifecycle
  - Location
  - Behavior

- Compared to procedural programming,
  - Objects lead to a different program structure
  - Objects lead to a different execution model

Object Identity: Example

- Consider
  r = l.rest( ); r.set(4711); **int** i = l.next.get();





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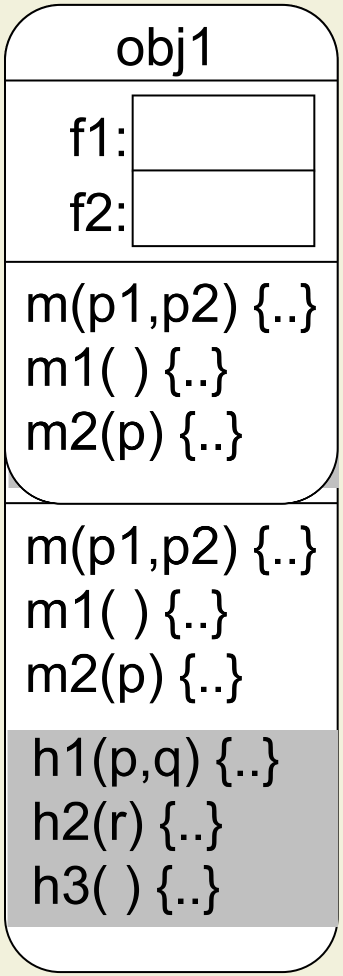
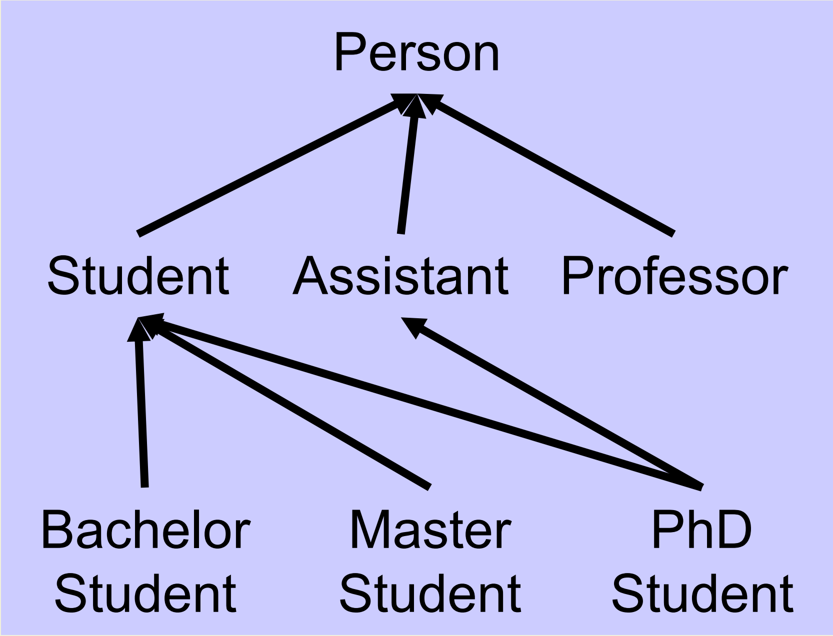
Core Concept 2: Interfaces and Encapsulation

- Objects have well-defined interfaces
  - Publicly accessible fields
  - Publicly accessible methods
- Implementation is hidden behind interface
  - Encapsulation
  - Information hiding
- Interfaces are the basis for documenting behavior



Core Concept 3: Classification and Polymorphism

- Classification: Hierarchical structuring of objects
- Objects belong to different classes simultaneously
- Substitution principle: Subtype objects can be used wherever supertype objects are expected



Arrows represent the “is-a” relation

Polymorphism

- Definition of *Polymorphism*:
  The quality of being able to assume different forms
  [Merriam-Webster Dictionary]

- In the context of programming:
  A program part is polymorphic if it can be used for objects of several classes

Subtype Polymorphism

- Subtype polymorphism is a direct consequence of the substitution principle
  - Program parts working with supertype objects work as well with subtype objects
  - Example: printAll can print objects of class Person, Student, Professor, etc.

- Other forms of polymorphism (not core concepts)
  - Parametric polymorphism (generic types)
  - Ad-hoc polymorphism (method overloading)

Parametric Polymorphism: Example

```
class List<G> {
  G[ ] elems;
  void append( G p ) { … }
}
```

```
List<String> myList;
myList = new List<String>( );
myList.append( “String” );
```

```
myList.append( myList );
```

- Parametric polymorphism uses type parameters
- One implementation can be used for different types
- Type mismatches can be detected at compile time

Ad-hoc Polymorphism: Example

```
class Any {
  void foo( Polar p ) { … }
  void foo( Coord c ) { … }
}
```

```
x.foo( new Coord( 5, 10 ) );
```

- Ad-hoc polymorphism allows several methods with the same name but different arguments
- Also called overloading
- No semantic concept: can be modeled by renaming easily

Specialization

- Definition of *Specialization*:
  Adding specific properties to an object or refining a concept by adding further characteristics.

- Start from general objects or types
- Extend these objects and their implementations (add properties)
- Requirement: Behavior of specialized objects is compliant to behavior of more general objects
- Program parts that work for the more general objects work as well for specialized objects

Example: Specialization

- Develop implementation for type Person
- Specialize it

```
class Person {
  String name;
  …
  void print( ) {
    System.out.println( name );
  }
}
```

Example: Specialization (cont'd)

- Inheritance of
  - Fields
  - Methods
- Methods can be overridden in subclasses

```
class Student extends Person {
  int regNum;
  …
  void print( ) {
    super.print( );
    System.out.println( regNum );
  }
}
```

```
class Professor extends Person {
  String room;
   …
  void print( ) {
    super.print( );
    System.out.println( room );
  }
}
```

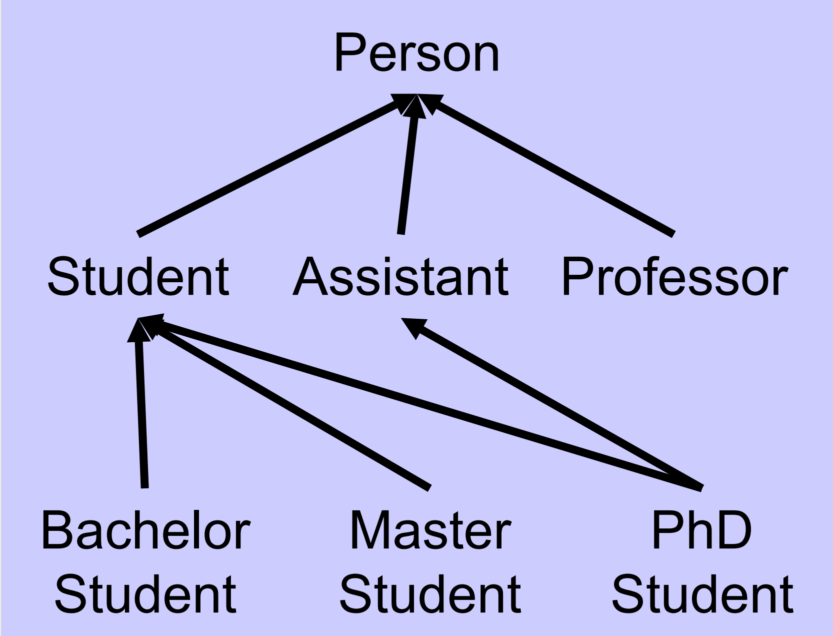
Core Concepts: Summary

- Core concepts of the OO-paradigm
  - Object model
  - Interfaces and encapsulation
  - Classification and polymorphism
- Core concepts are abstract concepts to meet the new requirements
- To apply the core concepts we need ways to express them in programs
- Language concepts enable and facilitate the application of the core concepts

1. Introduction

Example: Dynamic Method Binding

- Classification and polymorphism
  - Algorithms that work with supertype objects can be used with subtype objects
  - Subclass objects are specialized
- Dynamic binding: Method implementation is selected at run time, depending on the type of the receiver object




```
void printAll( Person[ ] l ) {
  for (int i=0; l[ i ] != null; i++)
    l[ i ] . print( );
}
```

OO-Concepts and Procedural Languages

- What we have seen so far
  - New concepts are needed to meet new requirements
  - Core concepts serve this purpose
  - Language concepts are needed to express core concepts in programs
- Open questions
  - Why do we need OO-programming languages?
  - Can't we use the language concepts as guidelines when writing procedural programs?
- Let's do an experiment …
  - Writing object-oriented programs in C

Types and Objects

- Declare types

```
typedef char*             String;
typedef struct sPerson Person;
```

- Declare records with
  - Fields
  - Methods (function pointers)

```
struct sPerson {
  String name;
  void   ( *print )( Person* );
  String ( *lastName )( Person* );
};
```

Methods and Constructors

- Define methods

```
void printPerson( Person *this ) {
  printf("Name: %s\n", this->name);
}

String LN_Person( Person *this )
  { … }
```

- Define constructors

```
Person *PersonC( String n ) {
  Person *this = (Person *)
              malloc( sizeof( Person ) );
  this -> name       = n;
  this -> print      = printPerson;
  this -> lastName  = LN_Person;
  return this;
}
```

Using the “Object”

- Declaration

```
struct sPerson {
  String name;
  void    ( *print )( Person* );
  String  ( *lastName )( Person* );
};
```

- Use constructors, fields, and methods

```
Person *p;
p = PersonC( “Tony Hoare“ );
p->name = p->lastName( p );
p->print( p );
```

Inheritance and Specialization

- Copy code
- Adapt function signatures

```
typedef struct sStudent Student;
struct sStudent {
  String name;
  void    ( *print )( Student* );
  String  ( *lastName )( Student* );
  int regNum;
};
```

- Define specialized methods

```
void printStudent( Student *this ) {
  printf("Name: %s\n", this->name);
  printf("No: %d\n", this->regNum);
}
```

Inheritance and Specialization (cont'd)

- Reuse LN_Person for Student
- View Student as Person (cast)

```
Student *StudentC( String n, int r ) {
  Student *this = (Student *)
            malloc( sizeof( Student ) );

  this -> name       = n;
  this -> print      = printStudent;

  this -> lastName   =
    (String (*)(Student*)) LN_Person;
  this -> regNum     = r;

  return this;
}
```

Subclassing and Dynamic Binding

- Student has all fields and methods of Person
- Casts are necessary

```
Student *s;
Person *p;
s = StudentC( "Susan Roberts", 0 );
p = (Person *) s;
p -> name = p -> lastName( p );
p -> print( p );
```

- Array l can contain Person and Student objects
- Methods are selected dynamically

```
void printAll( Person **l ) {
  int i;
  for ( i=0; l[ i ] != NULL; i++ )
    l[ i ] -> print( l[ i ] );
}
```

Discussion of the C Solution: Pros

- We can express objects, fields, methods, constructors, and dynamic method binding
- By imitating OO-programming, the union in Person and the switch statement in printAll became dispensable
- The behavior of reused code (Person, printAll) can be adapted (to introduce Student) without changing the implementation

Discussion of the C Solution: Cons

- Inheritance has to be replaced by code duplication
- Subtyping can be simulated, but it requires
  - Casts, which is not type safe
  - Same memory layout of super and subclasses (same fields and function pointers in same order), which is extremely error-prone
- C-solution includes undefined behavior (it violates the strict aliasing rule)
- Appropriate language support is needed to apply object-oriented concepts

A Java Solution

```
class Person {
  String name;
  void print( ) {
    System.out.println( "Name: " +
     name );
  }
  String lastName( ) { … }
  Person( String n ) { name = n; }
}
```

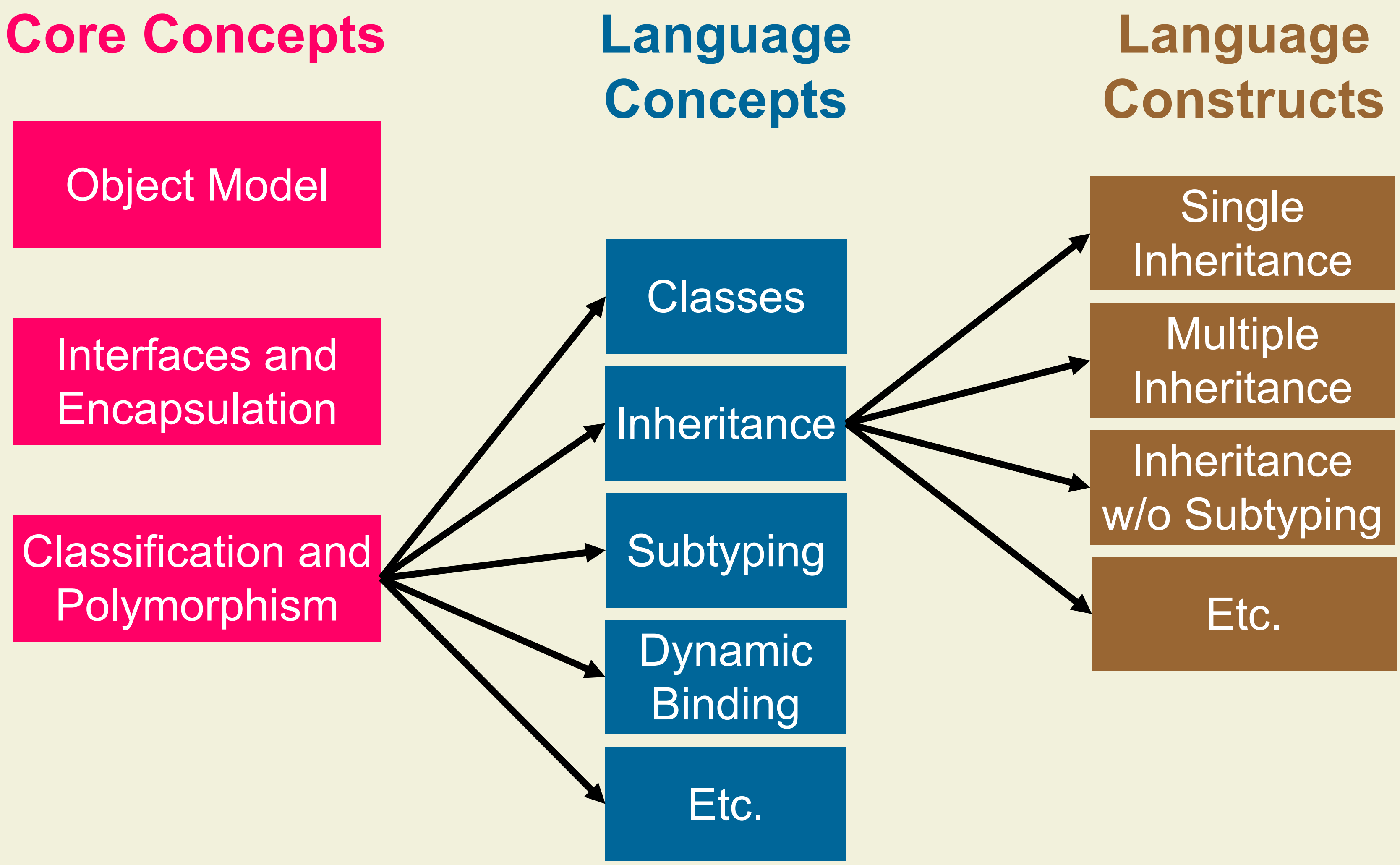
```
void printAll( Person[ ] l ) {
  for (int i=0; l[ i ] != null; i++)
    l[ i ].print( );
}
```

```
class Student extends Person {
  int regNum;
  void print( ) {
    super.print( );
    System.out.println( "No: " +
     regNum );
  }
  Student( String n, int i ) {
    super( n );
    regNum = i;
  }
}
```

Discussion of the Java Solution

- The Java solution uses
  - Inheritance to avoid code duplication
  - Subtyping to express classification
  - Overriding to specialize methods
  - Dynamic binding to adapt reused algorithms
- Java supports the OO-language concepts
- The Java solution is
  - Simpler and smaller
  - Easier to maintain (no duplicate code)
  - Type safe

Concepts: Summary



1. Introduction

After this Course, you should be able

- To understand the core and language concepts
- To understand language design trade-offs
- To compare OO-languages

- To learn new languages faster
- To apply language concepts and constructs correctly

- To write better object-oriented programs

Approach

- We discuss the
  - Concepts of
    as opposed to implementations, etc.
  - Object-Oriented
    as opposed to procedural, declarative
  - Programming
    as opposed to analysis, design, etc.
- We study and compare solutions in different languages such as C++, C#, Eiffel, Java, Python, and Scala
  - Java is used for most examples and exercises
- We look at code and analyze programs

Course Outline

2. Types and Subtyping
3. Inheritance
4. Static Safety
5. Parametric Polymorphism
6. Object Structures and Aliasing
7. Extended Typing
8. Object and Class Initialization
9. Reflection

Exams

- Mid-term exam
  - Written (45 mins)
  - 20% of the overall grade, bonus only
  - Friday, November 11, 12:15 – 13:00
  - No registration required
- End-term exam
  - Written (2 hours)
  - Thursday, December 22, 10:15 – 12:15
  - Registration required
- Exams will be closed-book

Course Infrastructure

- Web page:
  www.pm.inf.ethz.ch/education/courses/COOP.html

- Slides will be available on the web page two days before the lecture
  - Exercise assignments and solutions are published on Friday

- Responsible assistant:
  João Pereira
  joao.pereira@inf.ethz.ch

Exercise Sessions

- Friday, starting September 30
- 8:15 – 10:00 or 10:15 – 12:00
- In person (CAB/CHN)
- Registration required by Friday, September 23: https://forms.gle/DtpL8mzbkbngWTcy7

1. Introduction

What is a Good OO-Language?

- One that many people use?
  - No!
    (Or do you think JavaScript
    is a good language?)

- One that makes programmers productive?
  - No! (Or would you feel good if the Airbus flight controller was written in Python?)

- A good language should resolve design trade-offs in a way suitable for its application domain

Design Goals: Simplicity

- Syntax and semantics can easily be understood by users and implementers of the language
- But not small number of constructs
- Simple languages: Pascal, C, Java 1.0

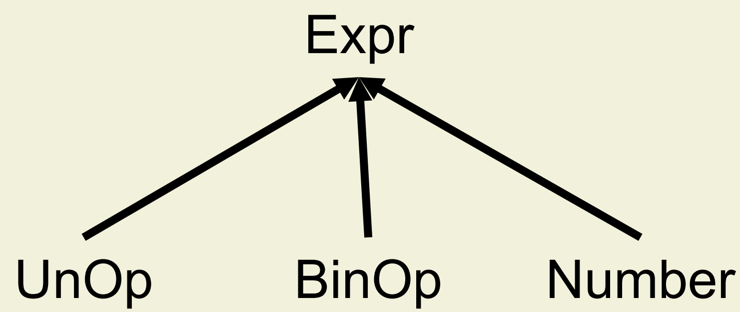
```
factorial ( i: INTEGER ): INTEGER
  require 0 <= i
once
  if i <= 1 then Result := 1
  else
    Result := i
    Result := Result * factorial ( i – 1 )
  end
end
```

Eiffel

- It took over 10 years to find out that the Java 5 type system (generics) is not decidable (and unsound)

Design Goals: Expressiveness

- Language can (easily) express complex processes and structures



- Expressive languages: C#, Scala, Python
- Often conflicting with simplicity

```
def simplify( expr: Expr ): Expr =
expr match {
  case UnOp( “–“, UnOp("–“,e) ) => e
  case BinOp( "+", e, Number(0) ) => e
  case BinOp( “*", e, Number(1) ) => e
  case _ => expr
}
```

Scala

Design Goals: (Static) Safety

- Language discourages errors and allows errors to be discovered and reported, ideally at compile time
- Safe languages: Java, C#, Rust, Scala
- Often conflicting with expressiveness and performance

Java

```
int foo( List<Integer> l, int i ) {
  if ( l.get( 0 ) != i ) return i / 5;
  else return 0;
}
```

```
List<Integer> l;
l = new ArrayList<Integer>();
l.add( 7 );
foo( l, “5“ );
```

Python

```
def foo( l, i ):
  if l[ 0 ] != i: return i / 5
  else: return 0
```

```
l = [ ]
l.append( 7 )
foo( l, “5“ )
```

Design Goals: Modularity

- Language allows modules to be type-checked and compiled separately
- Modular languages: Java, C#, Scala
- Often conflicting with expressiveness and performance

C++

```
template<class T> class C {
public:
  int foo( T p ) { return p->bar( ); };
};
```

```
class D { }

int main( int argc, char* argv[ ] ) {
  C<D*> c;
  int t = c.foo( new D() );
  return 0;
}
```

Design Goals: Performance

- Programs written in the language can be executed efficiently
- Efficient languages: C, C++, Rust
- Often conflicting with safety and simplicity

C++ arrays

- Sequence of memory locations
- Access is simple look-up (only 2-5 machine instructions)

Java arrays

- Sequence of memory locations plus length
- Access is look-up plus bound-check

Design Goals: Productivity

- Language leads to low costs of writing programs
- Closely related to expressiveness
- Languages for high productivity: Visual Basic, Python
- Often conflicting with static safety and performance

Python

```
def qsort( lst ):
  if len( lst ) <= 1:
    return lst

  pivot = lst.pop( 0 )

  greater_eq = \
    qsort( [ i for i in lst if i >= pivot ] )
  lesser = \
    qsort( [ i for i in lst if i < pivot ] )

  return lesser + [ pivot ] + greater_eq
```

Design Goals: Backwards Compatibility

- Newer language versions work and interface with programs in older versions
- Backwards compatible languages: Java, C
- Often in conflict with simplicity, performance, and expressiveness

Java

```
class Tuple<T> {
  T first; T second;

  void set( T first, T second ) {
    this.first = first;
    this.second = second;
  }
}
```

```
class Client {
  static void main( String[ ] args ) {
    Tuple t = new Tuple();
    t.set( "Hello", new Client() );
  }
}
```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