Lecture 27 – Course Review

COSE212: Programming Languages

Jihyeok Park

2024 Fall

Goal of This Course

PLRG

Learn **Essential Concepts** of **Programming Languages**

- Why?
  - To **learn new programming languages** quickly.
  - To **evaluate** and pick the best language for a given task.
  - To **design** your own **specialized languages** for specific tasks.
- How?

By **Designing** Diverse **Programming Languages**

  - By **designing** programming languages in a **mathematical** way.
  - By **implementing** their **interpreters** using **Scala**.

Summary

(Part 1) Untyped Languages	(Part 2) Typed Languages
Arithmetic Expressions **AE** (Lecture 2 & 3)	

Summary

(Part 1) Untyped Languages	(Part 2) Typed Languages

Arithmetic Expressions

AE

(Lecture 2 & 3)

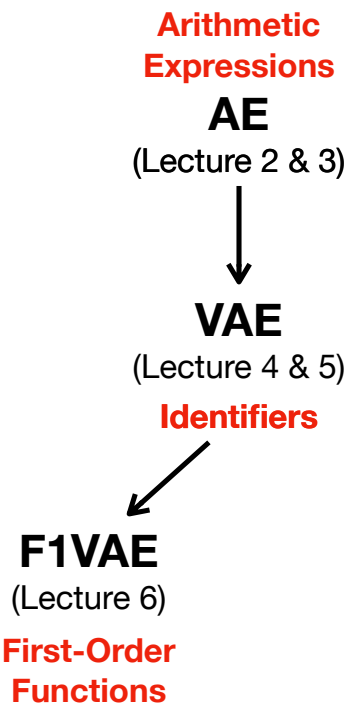
VAE

(Lecture 4 & 5)

Identifiers

Summary

(Part 1) Untyped Languages	(Part 2) Typed Languages



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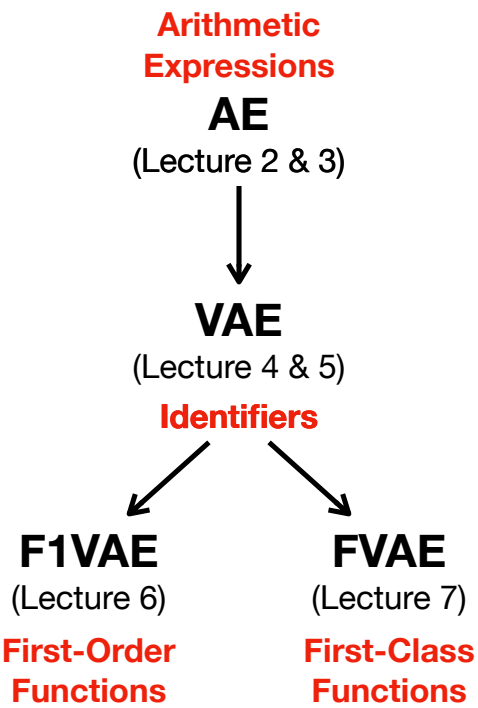

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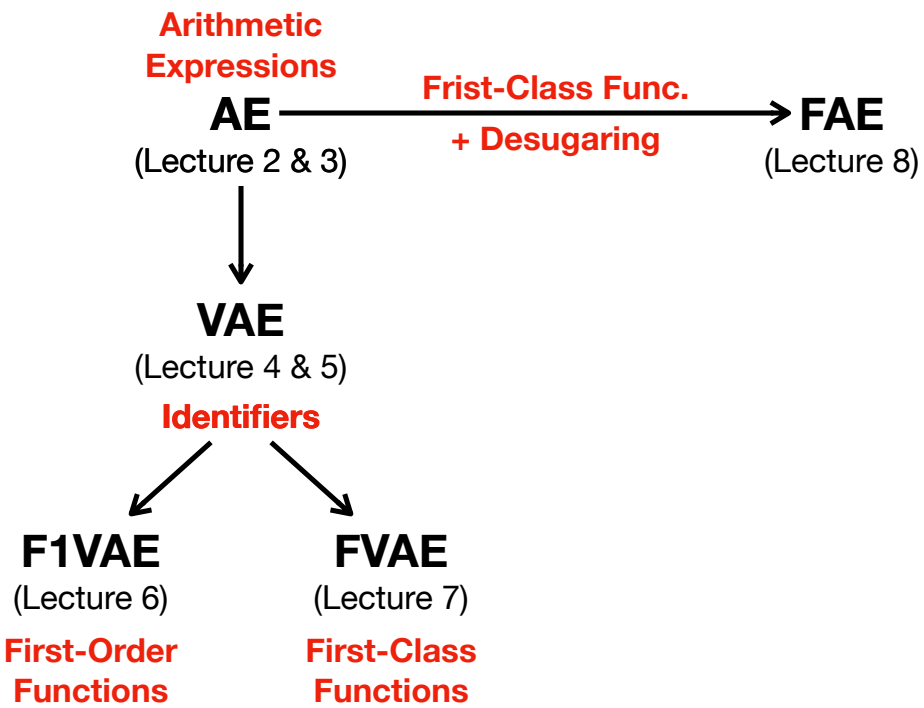

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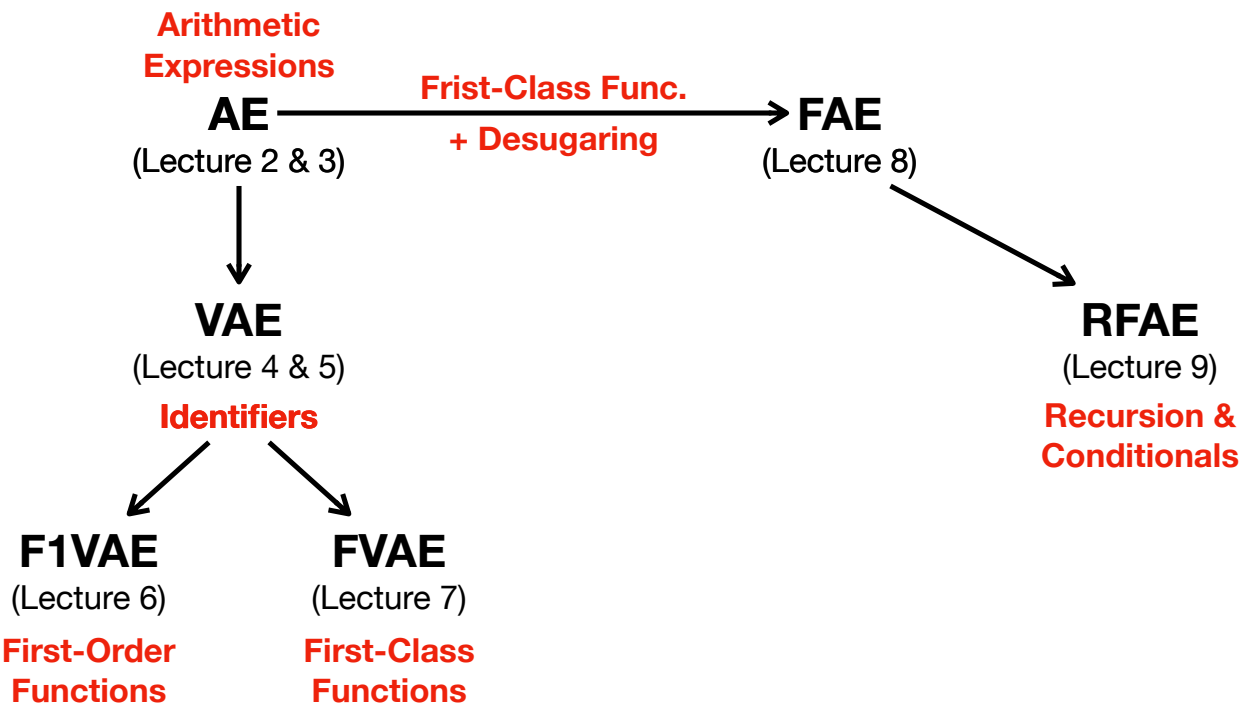

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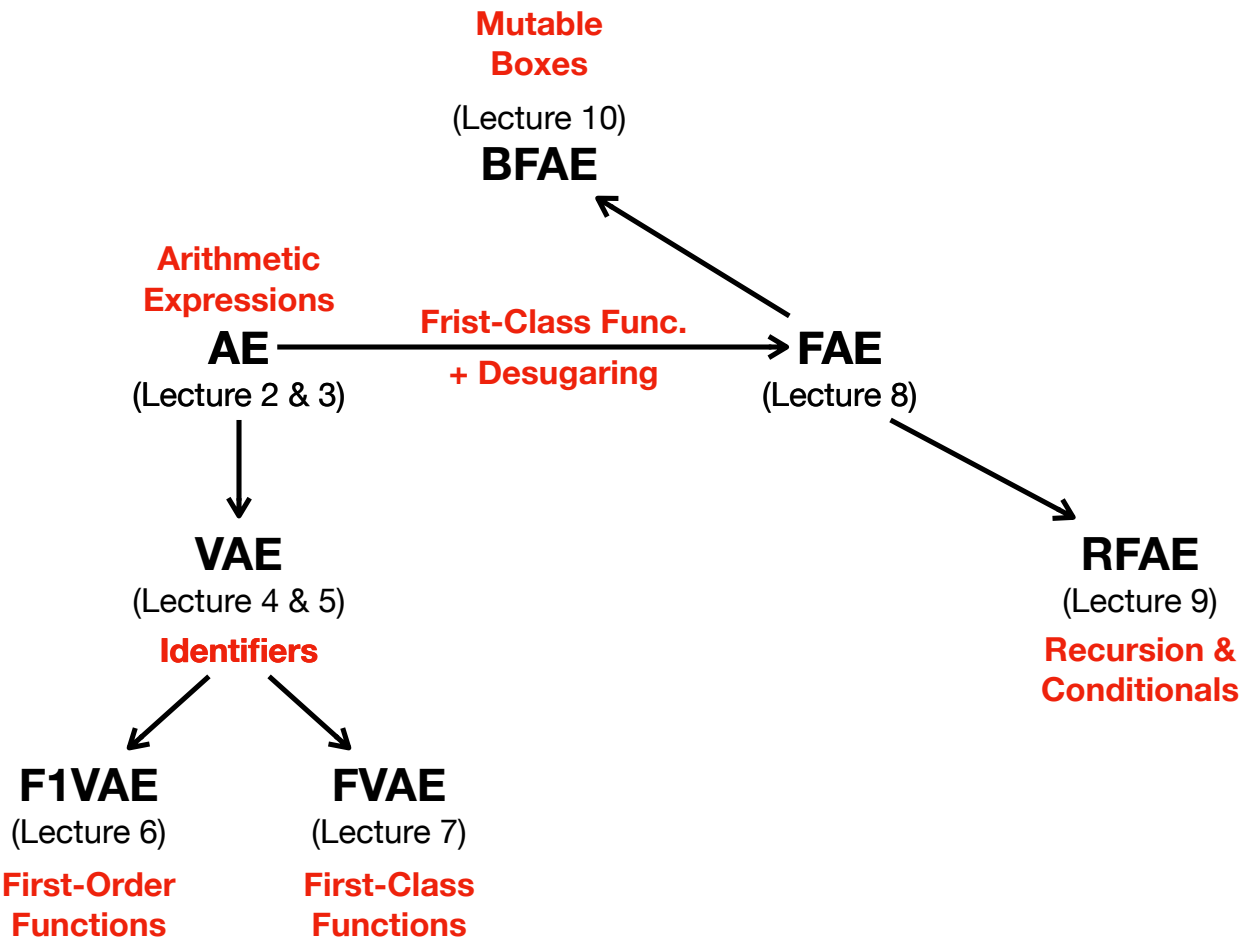

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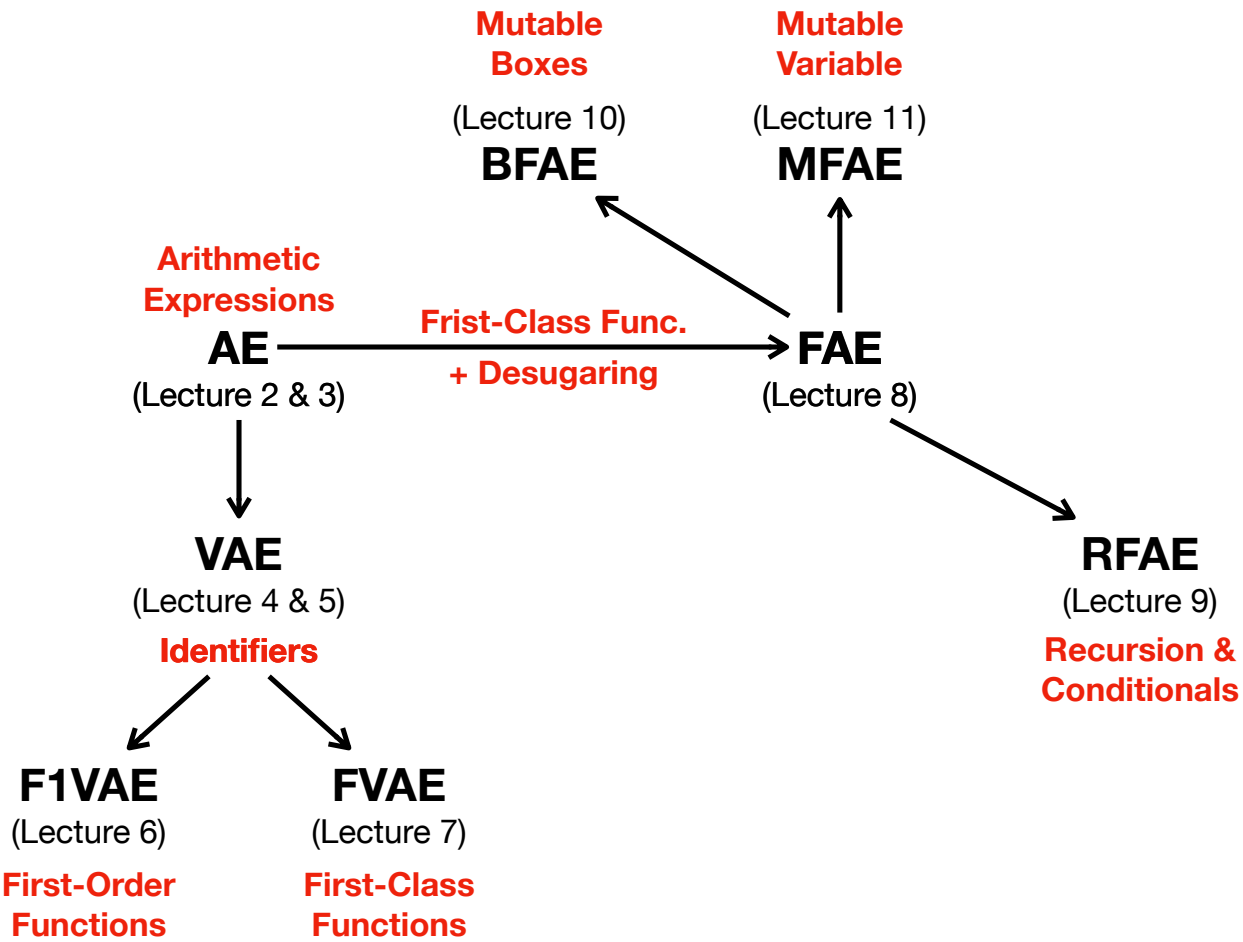

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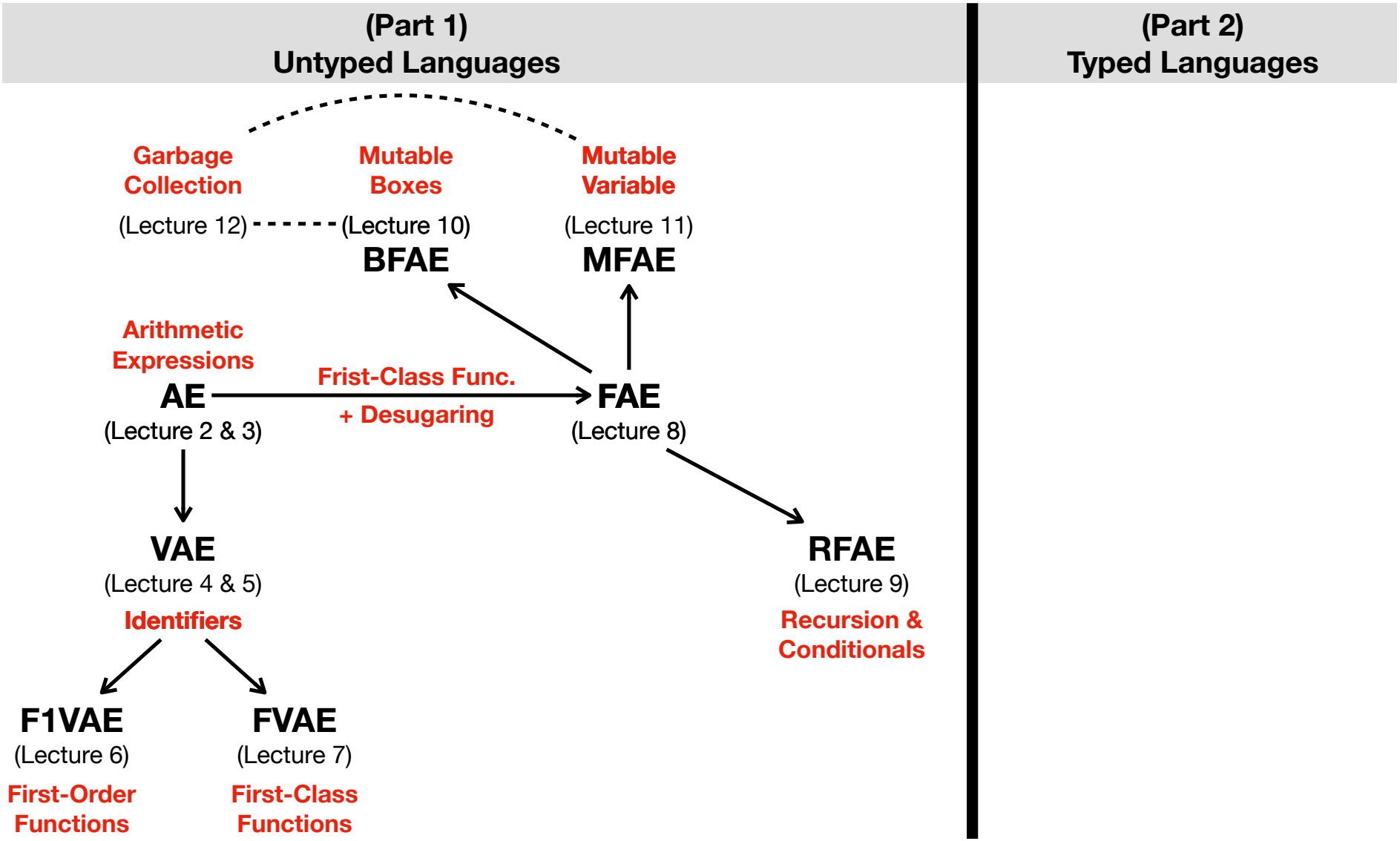
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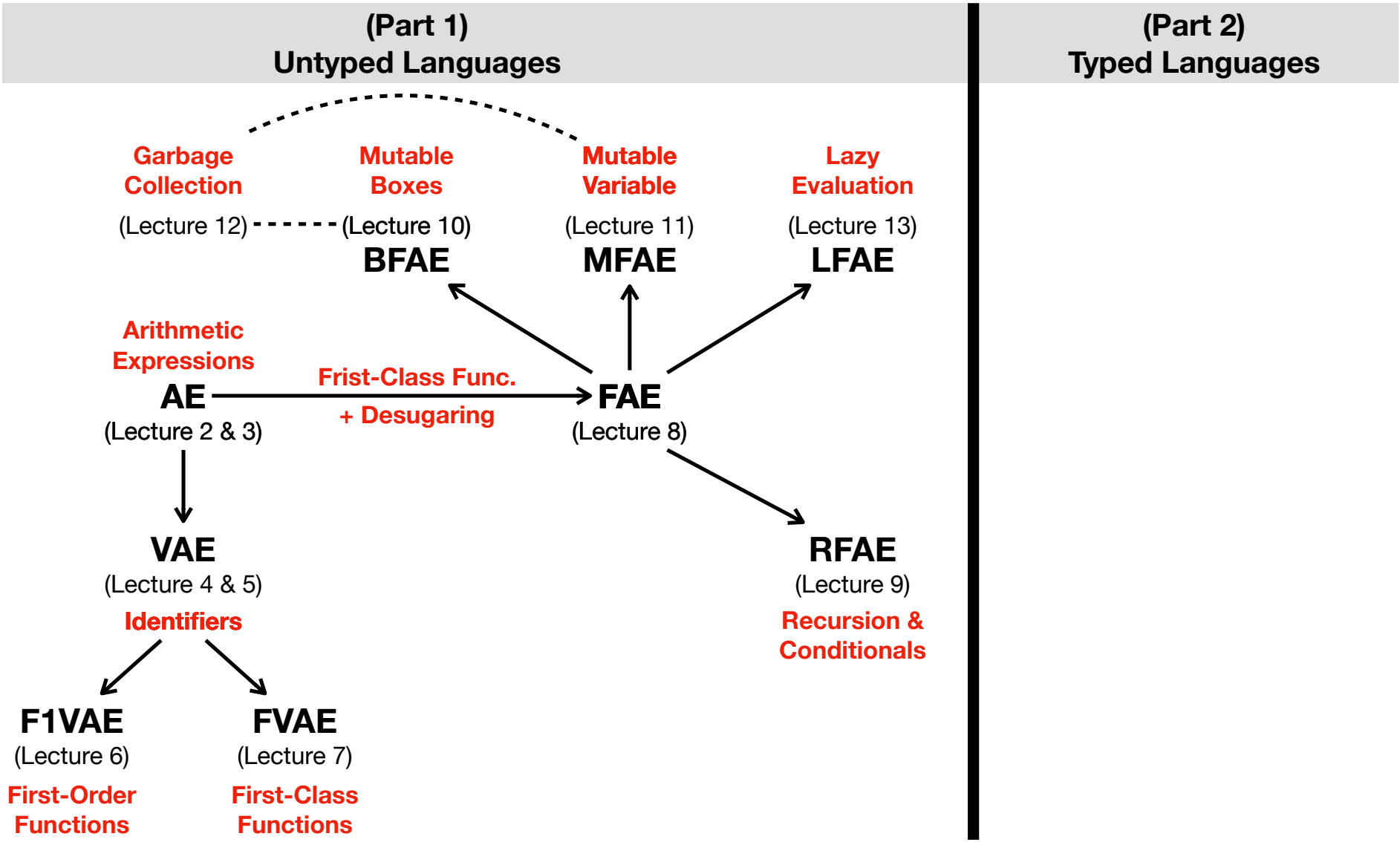
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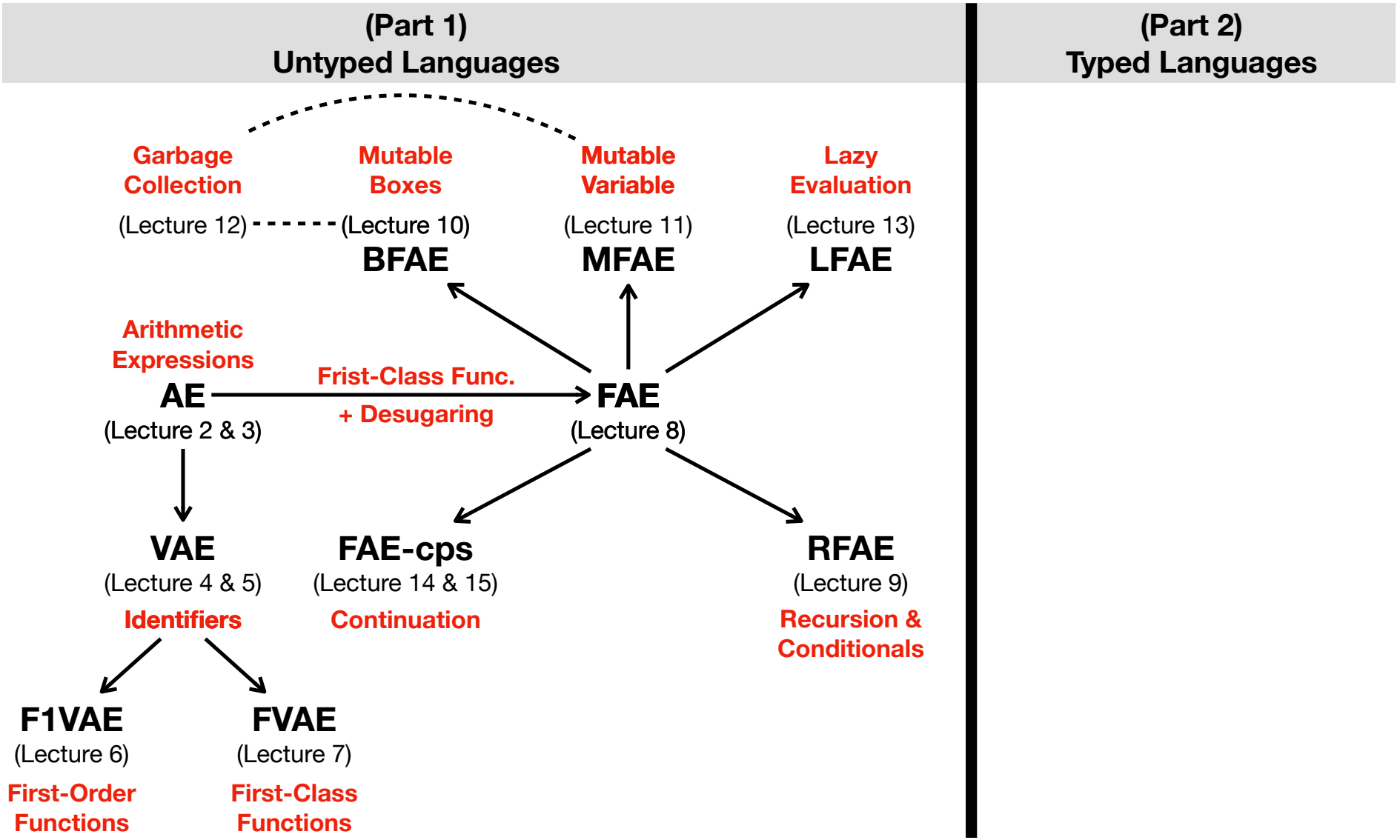
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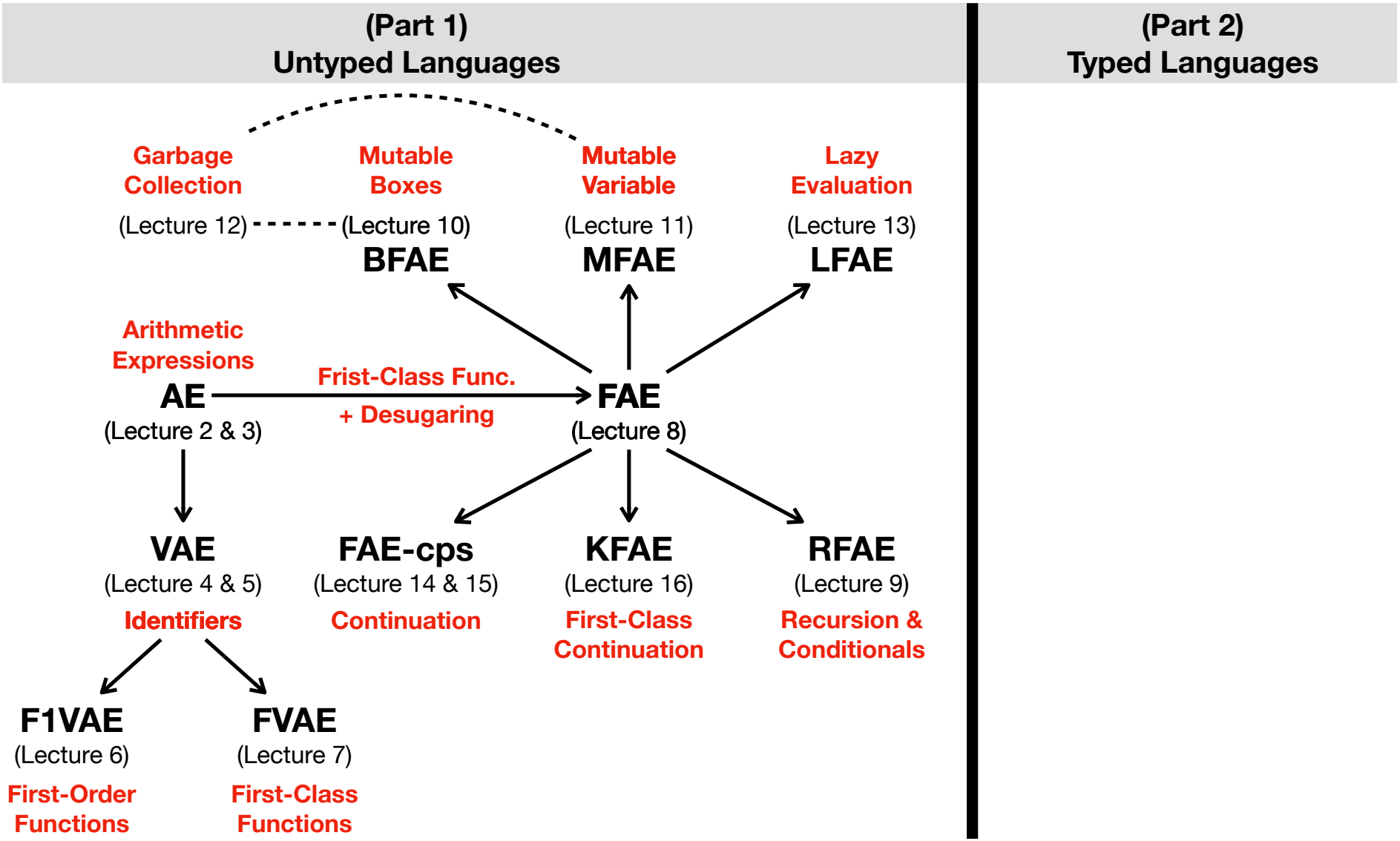
Summary

PLRG



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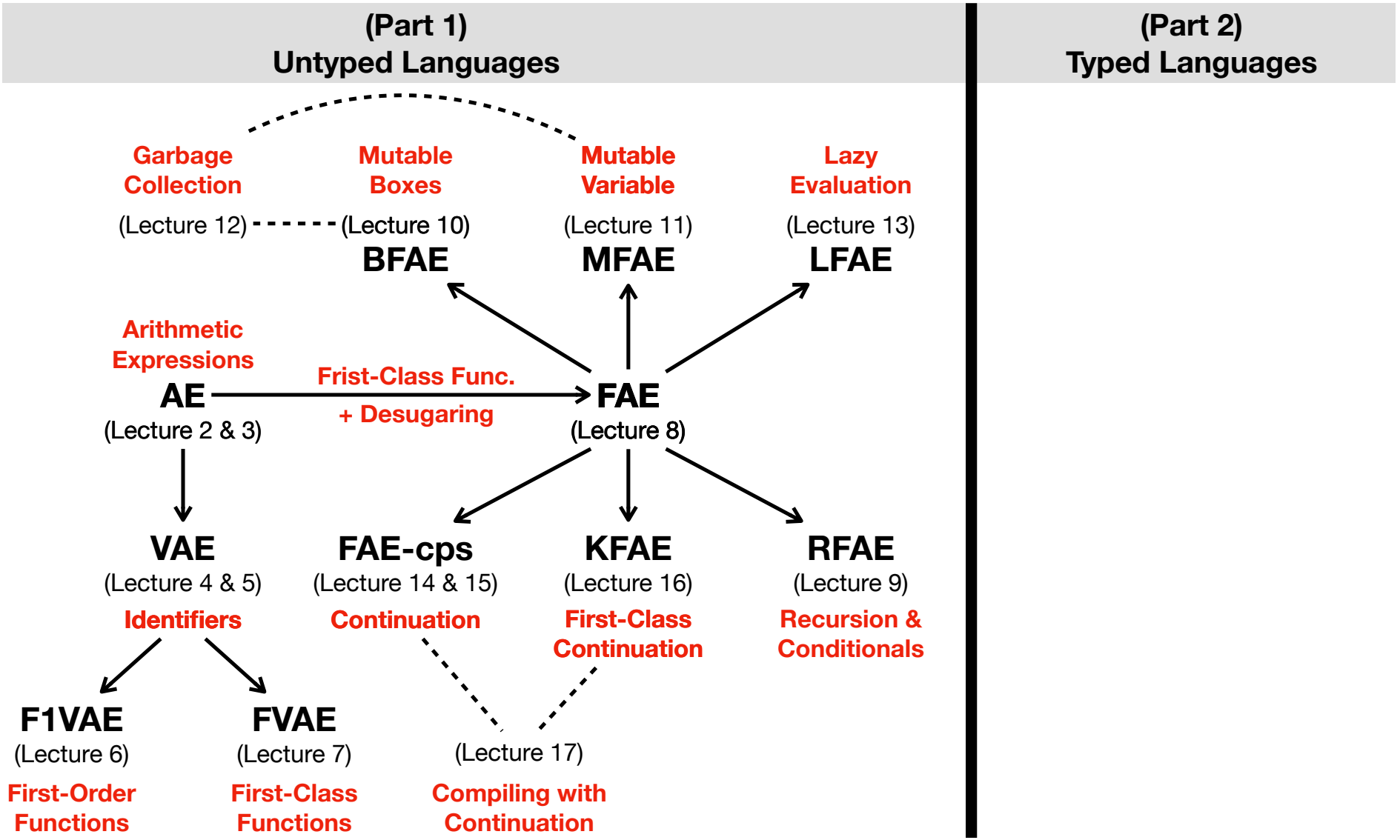
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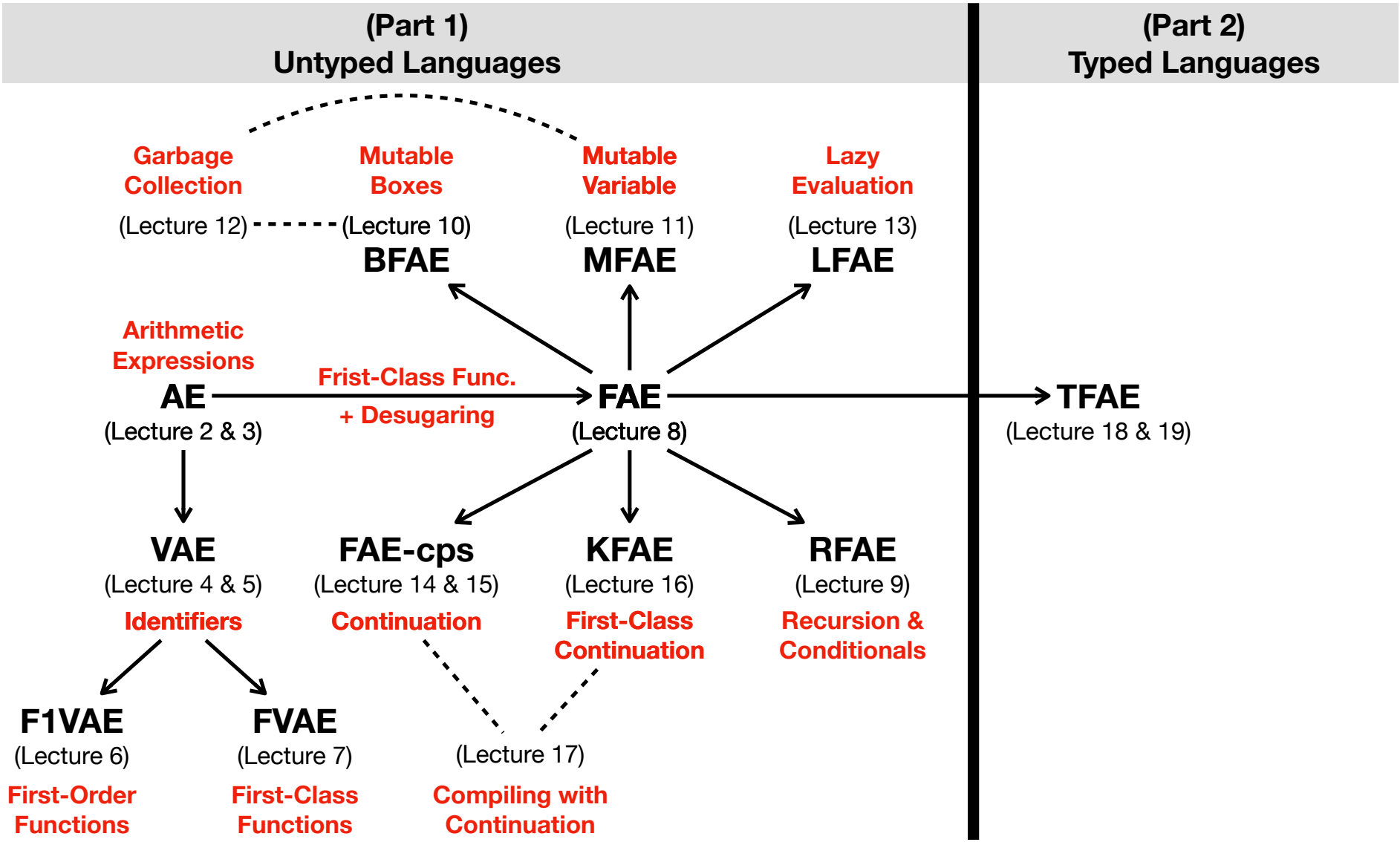
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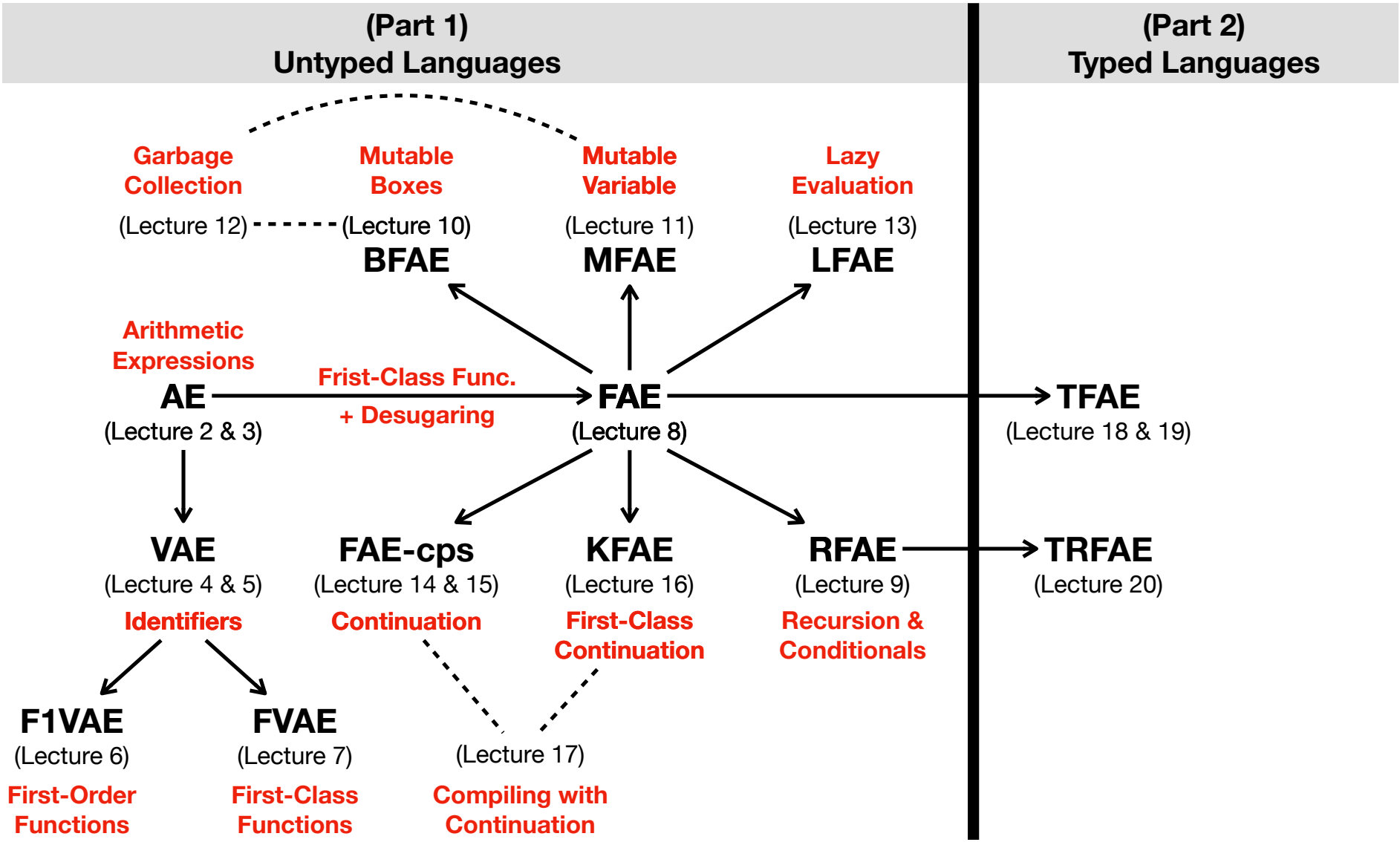
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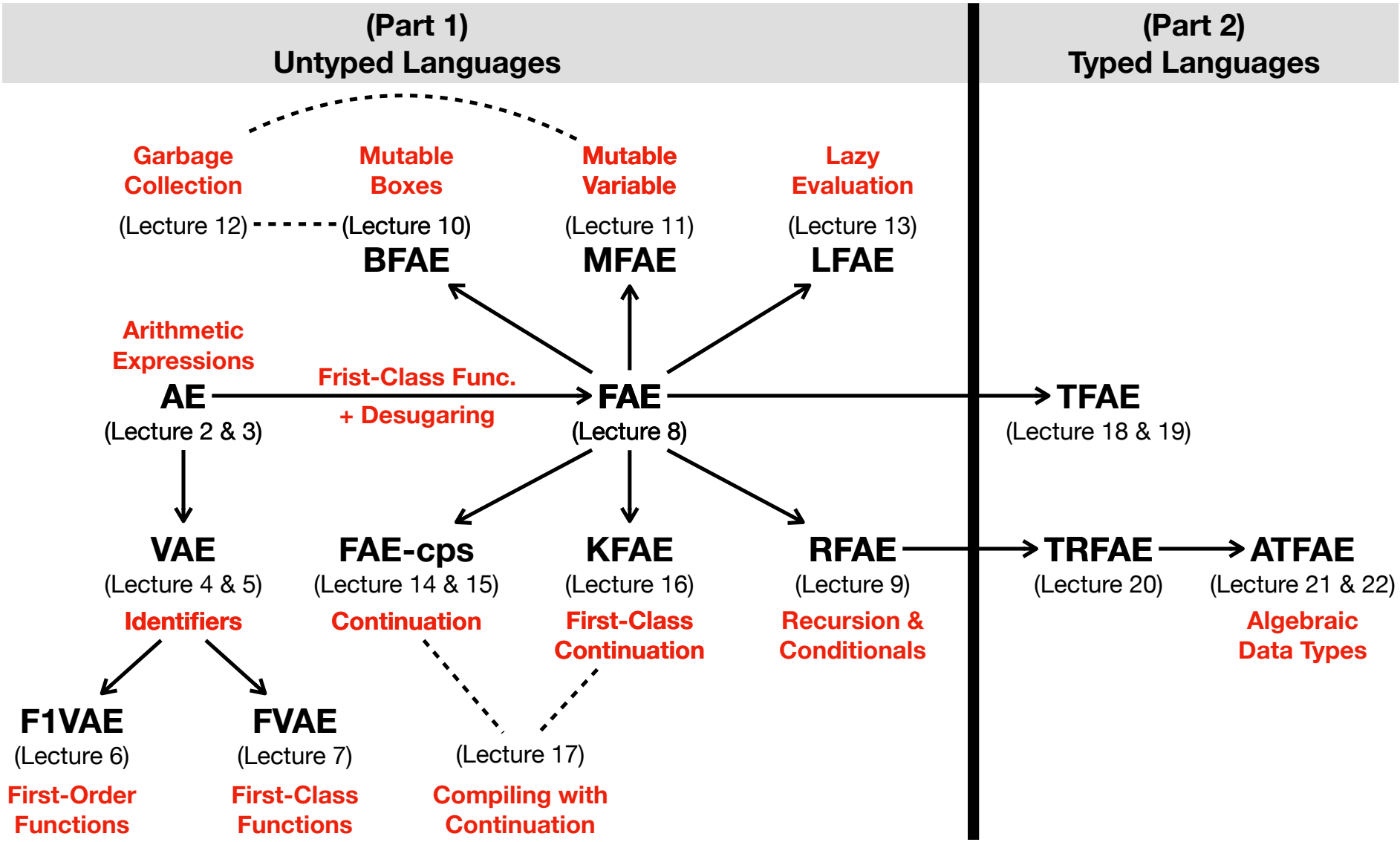
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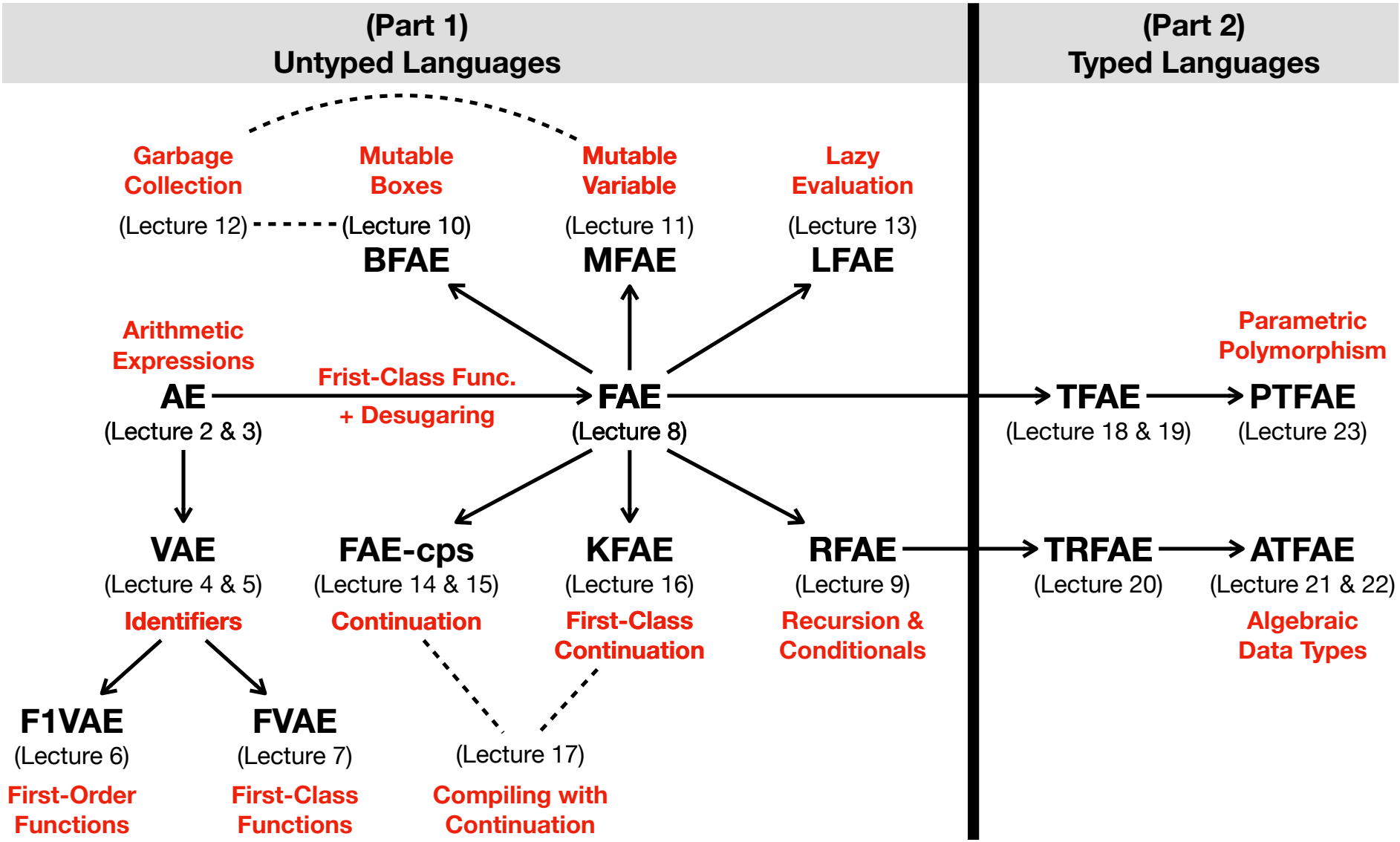
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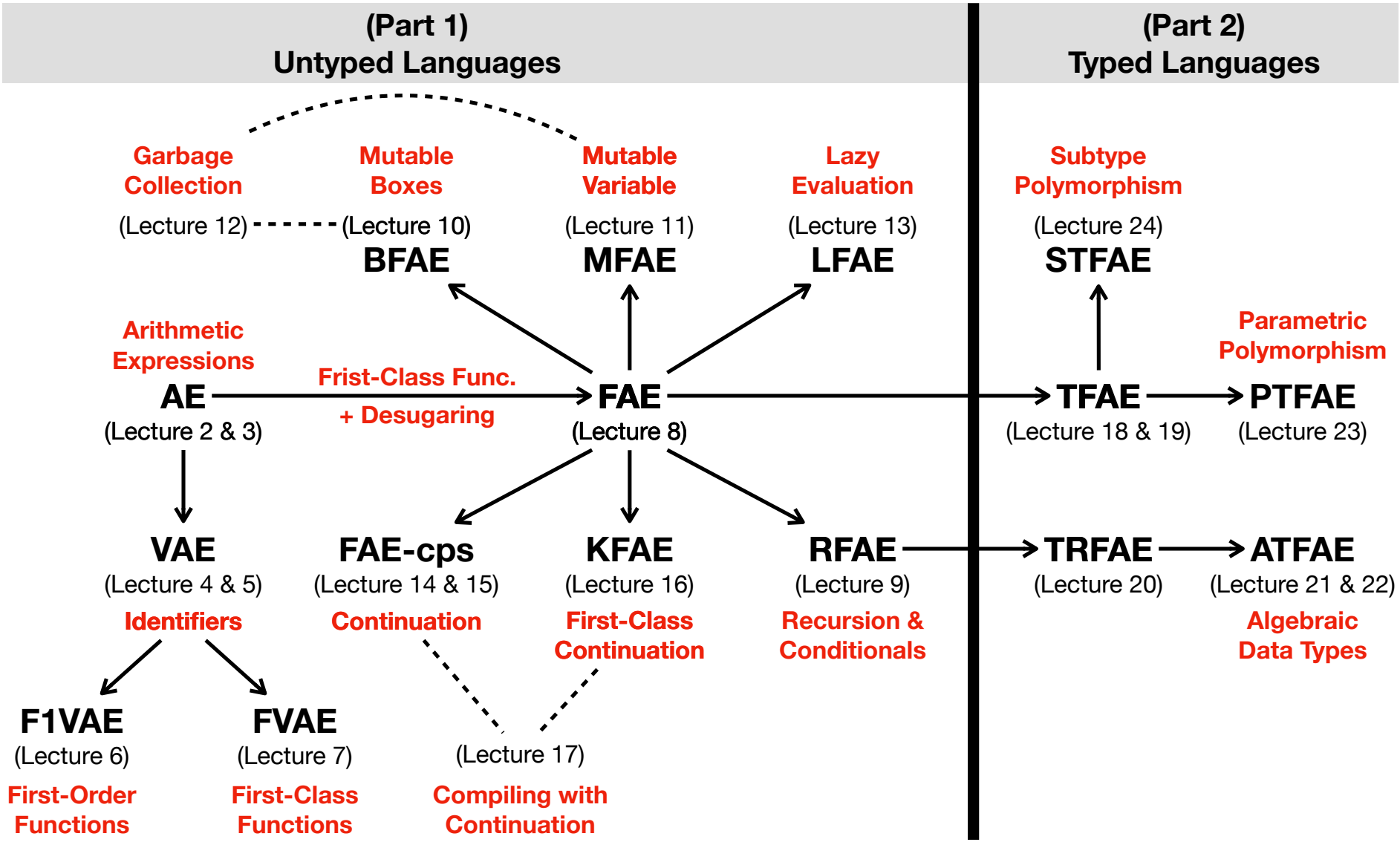
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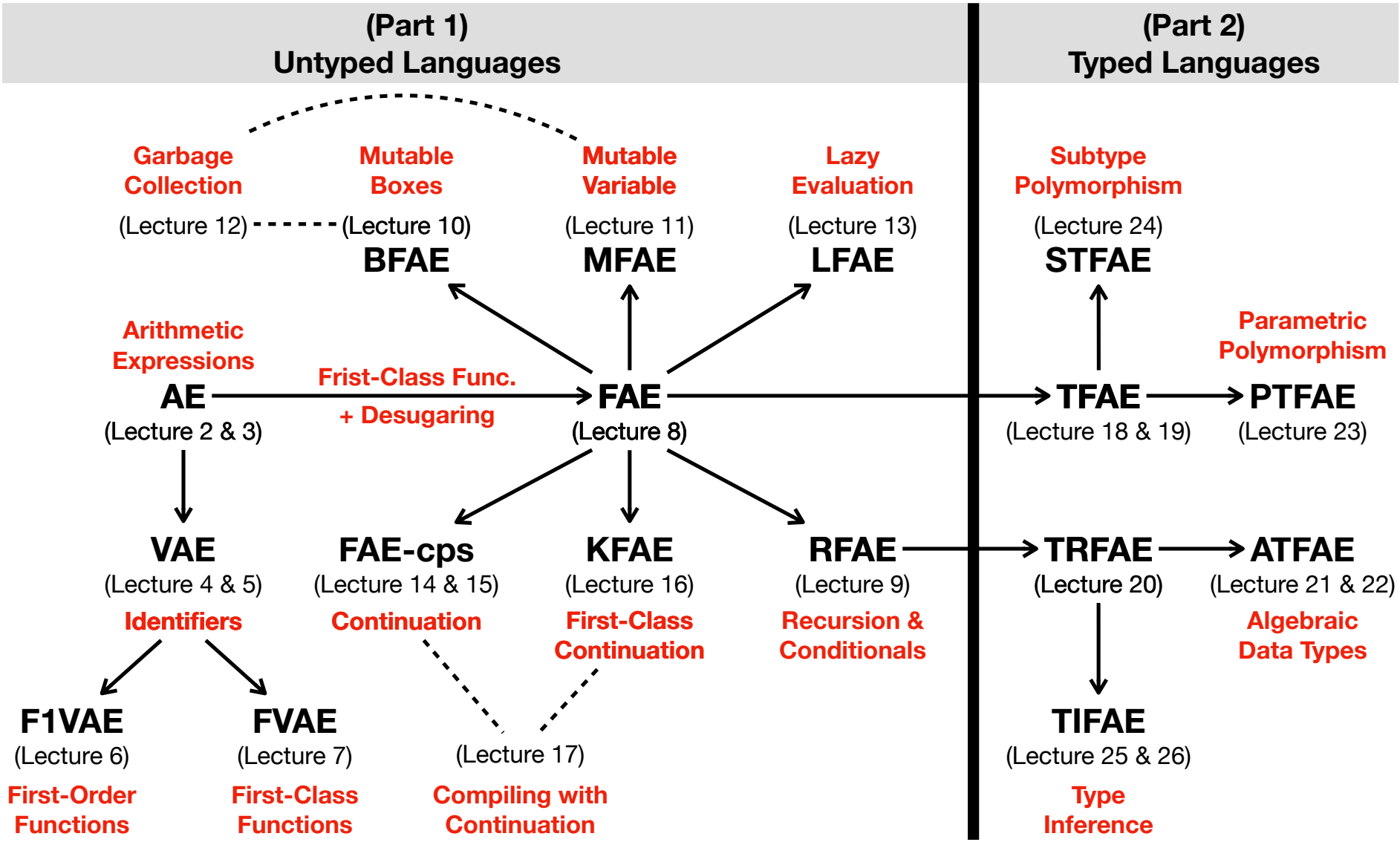
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TIFAE
(Lecture 25 & 26)
Type Inference

Applications of PL Foundations

PLRG

A deeper and broader understanding of programming languages can help you in:

- Software Engineering
- Software Testing
- Software Verification
- Software Analysis
- Software Security
- ...

Application 1 – Software Analysis

PLRG

We can develop a **static analyzer** for diverse purposes (e.g., optimization, understanding, bug detection, etc.) using the PL foundations.[1]

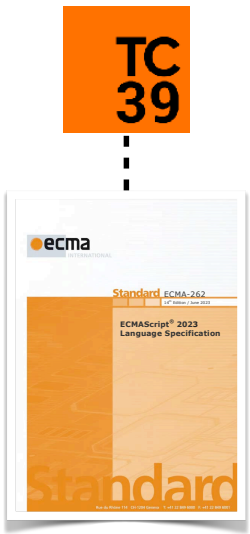
```
1 let x = /* 1 or 2 */;
2 let y = /* any str */;
3 let o = new Observable(subscriber => {
4   subscriber.next(1);
5   subscriber.next(2);
6   subscriber.next(3);
7 });
8 o.subscribe(k => x *= k); // x: 6 or 12
9 o.subscribe(k => y += k); // y: any str + "123"
```

An example of static analysis for a JavaScript program.

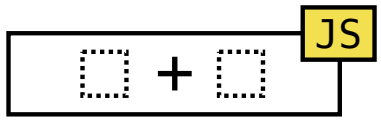
[1] [FSE'22] **Jihyeok Park**, Seungmin An, and Sukyoung Ryu, "Automatically Deriving JavaScript Static Analyzers from Specifications using Meta-level Static Analysis"

Application 2 – Mechanized Specification

To understand syntax and semantics of JavaScript language, we need to read the official language specification, called ECMA-262.[2]



ECMA-262
(JavaScript Spec.)



Syntax

AdditiveExpression`[Yield, Await]` :
MultiplicativeExpression`[?Yield, ?Await]`
AdditiveExpression`[?Yield, ?Await]` + *MultiplicativeExpression*`[?Yield, ?Await]`
AdditiveExpression`[?Yield, ?Await]` – *MultiplicativeExpression*`[?Yield, ?Await]`

Semantics

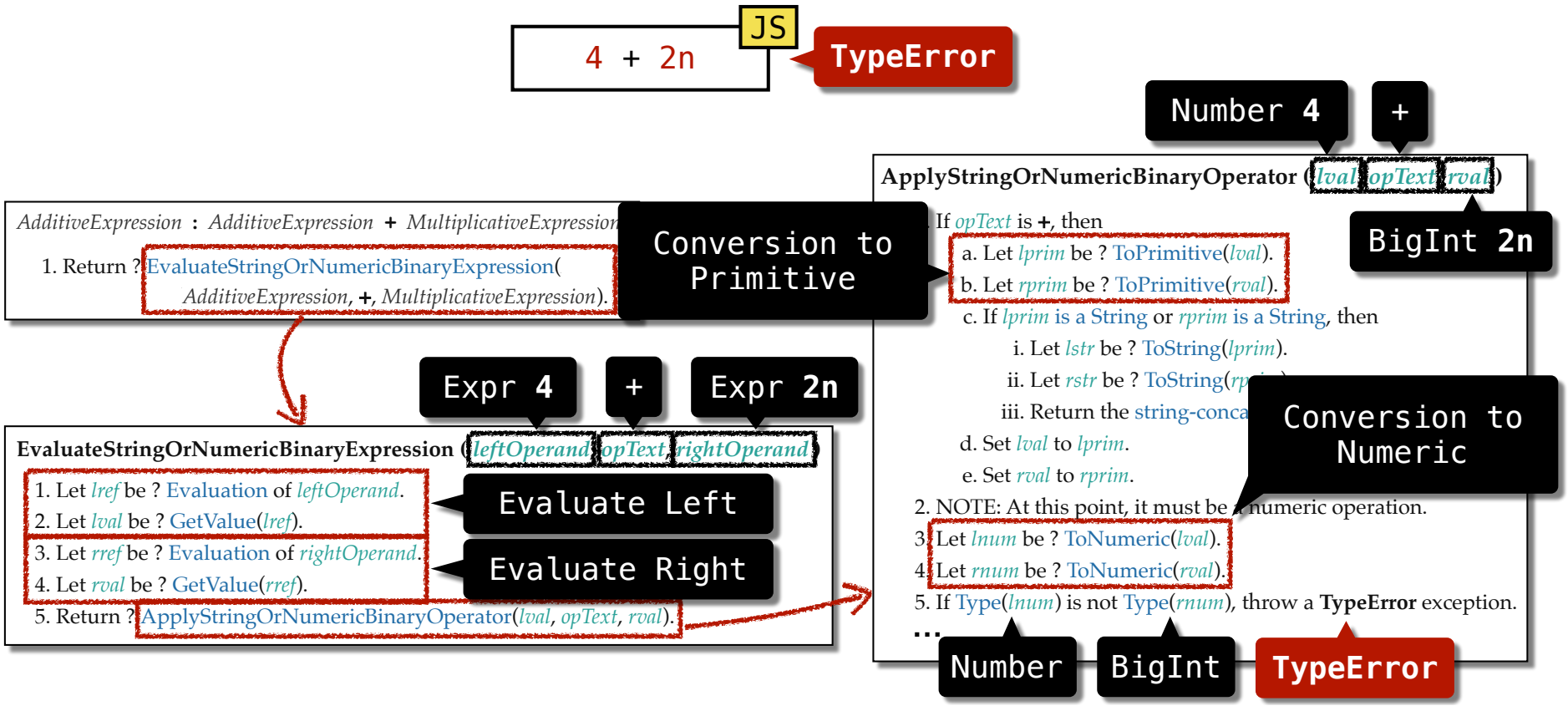
AdditiveExpression : *AdditiveExpression* + *MultiplicativeExpression*
1. Return ? EvaluateStringOrNumericBinaryExpression(*AdditiveExpression*, +, *MultiplicativeExpression*).

However, it consists of **800+ pages** with pseudocode-style algorithms as language semantics. It is laborious to understand and maintain the spec.

[2] https://tc39.es/ecma262/

Application 2 – Mechanized Specification

For example, we need to read the following steps to understand why the JavaScript program `4 + 2n` throws a run-time `TypeError`:



Application 2 – Mechanized Specification

To alleviate the problem, we **design** a programming language to represent algorithms in the spec and automatically **extract** the semantics from the language specification.[3]

Abstract algorithm for *ArrayLiteral* in ES13

ArrayLiteral : [*ElementList* , *Elision*$_{opt}$]

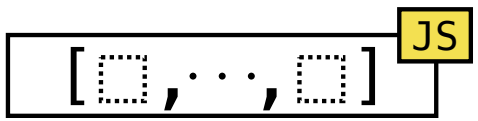
1. Let *array* be ! ArrayCreate(0).
2. Let *nextIndex* be ? ArrayAccumulation of *ElementList* with arguments *array* and 0.
3. If *Elision* is present, then
   a. Perform ? ArrayAccum
      with arguments *array*
4. Return *array*.

118 compile rules for steps in abstract algorithms

```
syntax def ArrayLiteral[2].Evaluation(
  this, ElementList, Elision
){
  let array = [! (ArrayCreate 0)]
  let nextIndex =
    [? (ElementList.ArrayAccumulation array 0)]
  if (! (= Elision absent))
    [? (Elision.ArrayAccumulation array nextIndex)]
  return array
}
```

IR$_{ES}$ function for *ArrayLiteral* in ES13

Semantics

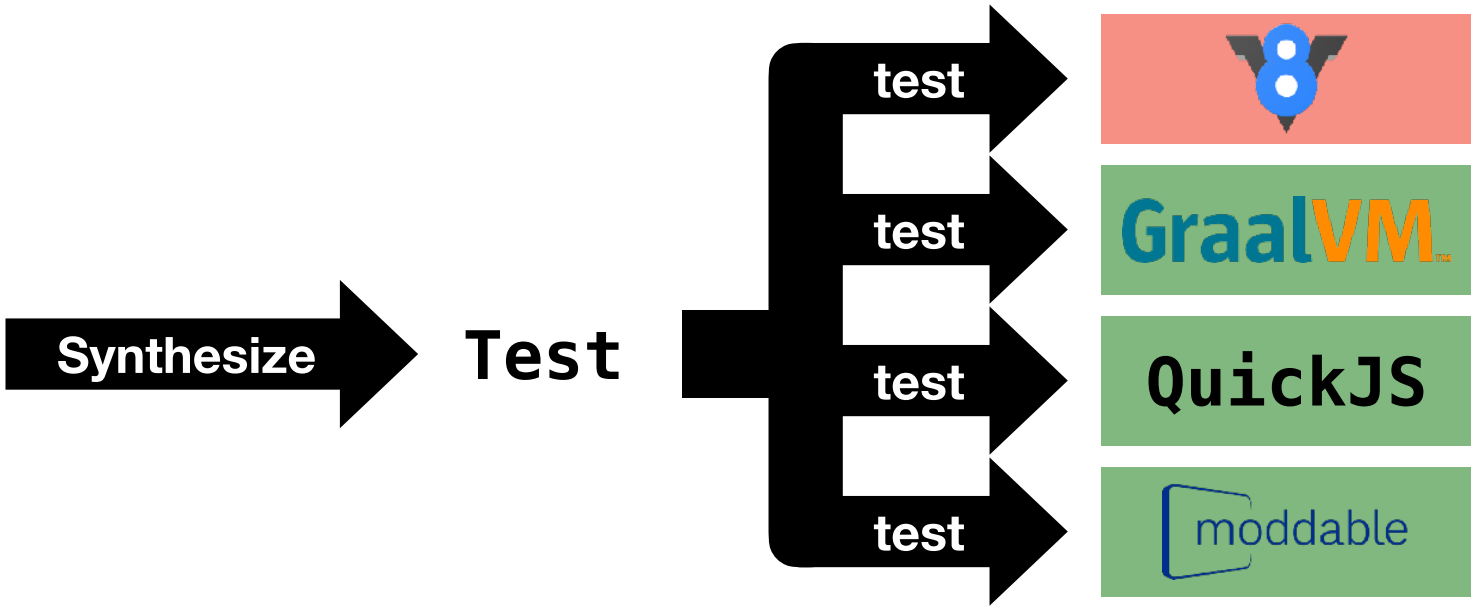


[3] [ASE'21] **Jihyeok Park**, Seungmin An, Wonho Shin, Yusung Sim, and Sukyoung Ryu, "JSTAR: JavaScript Specification Type Analyzer using Refinement"

Application 3 – Program Synthesis

Another application is to **synthesize** programs from specifications. For example, we can synthesize JavaScript programs to detect real-world bugs in JavaScript engines.[4]

ECMA-262
(JavaScript Spec.)



JavaScript Engines

[4] [PLDI'21] **Jihyeok Park**, Dongjun Youn, Kanguk Lee, and Sukyoung Ryu, "Feature-Sensitive Coverage for Conformance Testing of Programming Language Implementations"

Application 3 – Program Synthesis

PLRG

For example, we found a bug in the SpiderMonkey JavaScript engine (v107.0b4) used in Firefox by synthesizing the following JavaScript program from the JavaScript language specification.[5]

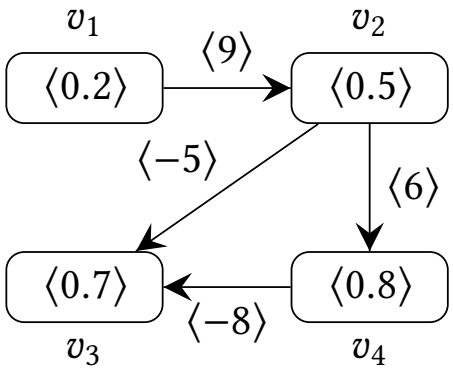
```
// [EXIT] normal
var x = (async function ([]) {})();
// Assertions
...
$assert.sameValue(Object.getPrototypeOf(globalThis["x"]), Promise.
    prototype);
$assert.sameValue(Object.isExtensible(globalThis["x"]), true);
$assert.notCallable(globalThis["x"]);
$assert.notConstructable(globalThis["x"]);
...
```

While it should be terminated normally, SpiderMonkey engine throws a run-time `TypeError` when executing the it.

[5] https://bugzilla.mozilla.org/show_bug.cgi?id=1799288

Application 4 – Explainable AI

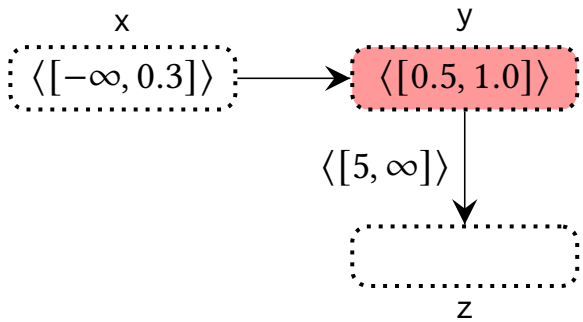
We can also use PL foundations to provide a better **explainability** for AI systems. For example, we can design a graph description language to explain the graph learning model.[6]



(a) A featured graph G_2

```
node x <[    , 0.3]>
node y <[0.5, 1.0]>
node z
edge (x, y)
edge (y, z) <[5, ]>
target node y
```

(b) A GDL program P_4



(c) A graphical representation of P_4

Fig. 3. A running example of GDL

Using the above graph description language, we can automatically generate explanations for the classification results of the graph learning model.

[6] [PLDI'24] Minseok Jeon, **Jihyeok Park**, and Hakjoo Oh, "PL4XGL: A Programming Language Approach to Explainable Graph Learning"

Final Exam

PLRG

- **Date:** 18:30 – 21:00 (150 min.), December 18 (Wed.).
- **Location:** 205, Woojung Hall of Informatics (우정정보관)
- **Coverage:** Lectures 14 – 26
- **Format:** closed book and closed notes
  - Fill-in-the-blank questions about the PL concepts.
  - Write the evaluation results of given expressions.
  - Draw derivation trees of given expressions.
  - Define the syntax or semantics of extended language features.
  - Define typing rules for the given language features.
  - etc.
- Note that there is **no class** on **December 16 (Mon.)**.

- I hope you enjoyed the class!

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