Generics

EECS3311 A & E: Software Design
Fall 2020

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Learning Objectives

Upon completing this lecture, you are expected to understand:

1. A ***general*** collection `ARRAY[ANY]`: storage vs. retrieval
2. A ***generic*** collection `ARRAY[G]`: storage vs. retrieval
3. Generics vs. Inheritance

Motivating Example: A Book of Any Objects

```
class BOOK
  names: ARRAY[STRING]
  records: ARRAY[ANY]
  -- Create an empty book
  make do ... end
  -- Add a name-record pair to the book
  add (name: STRING; record: ANY) do ... end
  -- Return the record associated with a given name
  get (name: STRING): ANY do ... end
end
```

Question: Which line has a type error?

```
1  birthday: DATE; phone_number: STRING
2  b: BOOK; is_wednesday: BOOLEAN
3  create {BOOK} b.make
4  phone_number := "416-677-1010"
5  b.add ("SuYeon", phone_number)
6  create {DATE} birthday.make(1975, 4, 10)
7  b.add ("Yuna", birthday)
8  is_wednesday := b.get("Yuna").get_day_of_week = 4
```

Motivating Example: Observations (1)

- In the `BOOK` class:
  - In the attribute declaration

    ```
    records: ARRAY[ANY]
    ```

    - ***ANY*** is the most general type of records.
    - Each book instance may store any object whose *static type* is a *descendant class* of ***ANY***.
  - Accordingly, from the return type of the `get` feature, we only know that the returned record has the static type ***ANY***, but not certain about its *dynamic type* (e.g., `DATE`, `STRING`, *etc.*).
    ∴ a record retrieved from the book, e.g., `b.get("Yuna")`, may only be called upon features defined in its *static type* (i.e,. ***ANY***).
- In the tester code of the `BOOK` class:
  - In **Line 1**, the *static types* of variables `birthday` (i.e., `DATE`) and `phone_number` (i.e., `STRING`) are *descendant classes* of `ANY`.
    ∴ **Line 5** and **Line 7** compile.

Motivating Example: Observations (2)

Due to **polymorphism**, in a collection, the *dynamic types* of stored objects (e.g., `phone_number` and `birthday`) need not be the same.

- Features specific to the *dynamic types* (e.g., `get_day_of_week` of class `Date`) may be new features that are not inherited from `ANY`.
- This is why **Line 8** would fail to compile, and may be fixed using an explicit *cast*:

```
check attached {DATE} b.get("Yuna") as yuna_bday then
  is_wednesday := yuna_bday.get_day_of_week = 4
end
```

- But what if the *dynamic type* of the returned object is not a `DATE`?

```
check attached {DATE} b.get("SuYeon") as suyeon_bday then
  is_wednesday := suyeon_bday.get_day_of_week = 4
end
```

⇒ An *assertion violation* at *runtime*!

Motivating Example: Observations (2.1)

- It seems that a combination of `attached` check (similar to an `instanceof` check in Java) and type cast can work.
- Can you see any potential problem(s)?
- **Hints:**
  - Extensibility and Maintainability
  - What happens when you have a large number of records of distinct *dynamic types* stored in the book (e.g., `DATE`, `STRING`, `PERSON`, `ACCOUNT`, `ARRAY_CONTAINER`, `DICTIONARY`, *etc.*)? [all classes are descendants of ***ANY***]

Motivating Example: Observations (2.2)

Say a client stores 100 distinct record objects into the book.

```
rec1: C1
... -- declarations of rec2 to rec99
rec100: C100
create {C1} rec1.make(...) ; b.add(..., rec1)
... -- additions of rec2 to rec99
create {C100} rec100.make(...) ; b.add(..., rec100)
```

where ***static types*** `C1` to `C100` are *descendant classes* of `ANY`.

- *Every time* you retrieve a record from the book, you need to check "exhaustively" on its *dynamic type* before calling some feature(s).

```
-- assumption: 'f1' specific to C1, 'f2' specific to C2, etc.
if attached {C1} b.get("Jim") as c1 then
  c1.f1
... -- cases for C2 to C99
elseif attached {C100} b.get("Jim") as c100 then
  c100.f100
end
```

- Writing out this list multiple times is tedious and error-prone!

Motivating Example: Observations (3)

We need a solution that:

- Eliminates runtime assertion violations due to wrong casts
- Saves us from explicit `attached` checks and type casts

As a sketch, this is how the solution looks like:

- When the user declares a `BOOK` object `b`, they must commit to the kind of record that `b` stores at runtime.
  e.g., `b` stores either `DATE` objects (and its *descendants*) only or `String` objects (and its *descendants*) only, but *not a mix*.
- When attempting to store a new record object `rec` into `b`, if `rec`'s *static type* is not a *descendant class* of the type of book that the user previously commits to, then:
  - It is considered as a ***compilation error***
  - Rather than triggering a ***runtime assertion violation***
- When attempting to retrieve a record object from `b`, there is *no longer a need* to check and cast.
  ∵ *Static types* of all records in `b` are guaranteed to be the same.

Parameters

- In mathematics:
  - The same *function* is applied with different *argument values*.
    e.g., `2 + 3`, `1 + 1`, `10 + 101`, *etc.*
  - We *generalize* these instance applications into a definition.
    e.g., $+ : (\mathbb{Z} \times \mathbb{Z}) \rightarrow \mathbb{Z}$ is a function that takes two integer *parameters* and returns an integer.
- In object-oriented programming:
  - We want to call a *feature*, with different *argument values*, to achieve a similar goal.
    e.g., `acc.deposit(100)`, `acc.deposit(23)`, *etc.*
  - We *generalize* these possible feature calls into a definition.
    e.g., In class `ACCOUNT`, a feature `deposit(amount: REAL)` takes a real-valued *parameter*.
- When you design a mathematical function or a class feature, always consider the list of *parameters*, each of which representing a set of possible *argument values*.

Generics: Design of a Generic Book

```
class BOOK[ G ]
  names: ARRAY[STRING]
  records: ARRAY[ G ]
  -- Create an empty book
  make do ... end
  /* Add a name-record pair to the book */
  add (name: STRING; record: G ) do ... end
  /* Return the record associated with a given name */
  get (name: STRING): G do ... end
end
```

Question: Which line has a type error?

```
1  birthday: DATE; phone_number: STRING
2  b: BOOK[DATE] ; is_wednesday: BOOLEAN
3  create BOOK[DATE] b.make
4  phone_number = "416-67-1010"
5  b.add ("SuYeon", phone_number)
6  create {DATE} birthday.make (1975, 4, 10)
7  b.add ("Yuna", birthday)
8  is_wednesday := b.get("Yuna").get_day_of_week == 4
```

Generics: Observations

- In class `BOOK`:
  - At the class level, we *parameterize the type of records*:

    ```
    class BOOK[G]
    ```

  - Every occurrence of `ANY` is replaced by `E`.
- As far as a client of `BOOK` is concerned, they must *instantiate* `G`.
  ⇒ This particular instance of book must consistently store items of that instantiating type.
- As soon as `E` instantiated to some known type (e.g., `DATE`, `STRING`), every occurrence of `E` will be replaced by that type.
- For example, in the tester code of `BOOK`:
  - In **Line 2**, we commit that the book `b` will store `DATE` objects only.
  - **Line 5** fails to compile. [∵ `STRING` not **descendant** of `DATE`]
  - **Line 7** still compiles. [∵ `DATE` is **descendant** of itself]
  - **Line 8** does *not need* any `attached` check and type cast, and does *not cause* any runtime assertion violation.
    ∵ All attempts to store non-`DATE` objects are caught at ***compile time***.

Bad Example of using Generics

Has the following client made an appropriate choice?

```
book: BOOK[ANY]
```

NO!!!!!!!!!!!!!!!!!!!!!!!!

- It allows **all** kinds of objects to be stored.
  ∵ All classes are descendants of ***ANY***.
- We can expect **very little** from an object retrieved from this book.
  ∵ The ***static type*** of `book`'s items are ***ANY***, root of the class hierarchy, has the *minimum* amount of features available for use.
  ∵ Exhaustive list of casts are unavoidable.
  [***bad*** for extensibility and maintainability]

Instantiating Generic Parameters

- Say the **supplier** provides a generic `DICTIONARY` class:

```
class DICTIONARY[V, K] -- V type of values; K type of keys
  add_entry (v: V; k: K) do ... end
  remove_entry (k: K) do ... end
end
```

- **Clients** use `DICTIONARY` with different degrees of instantiations:

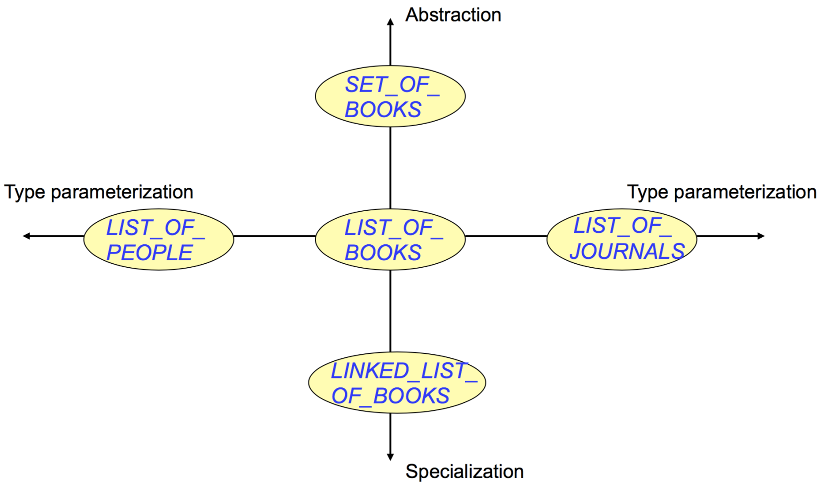
```
class DATABASE_TABLE[K, V]
  imp: DICTIONARY[V, K]
end
```

e.g., Declaring `DATABSE_TABLE[INTEGER, STRING]` instantiates `DICTIONARY[STRING, INTEGER]`.

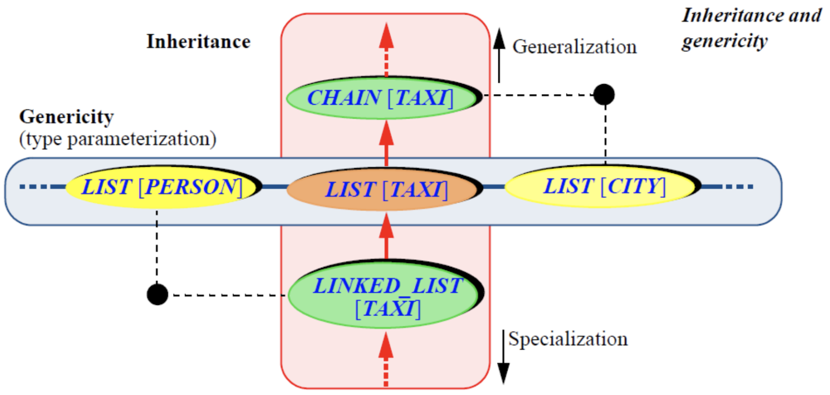
```
class STUDENT_BOOK[V]
  imp: DICTIONARY[V, STRING]
end
```

e.g., Declaring `STUDENT_BOOK[ARRAY[COURSE]]` instantiates `DICTIONARY[ARRAY[COURSE], STRING]`.

Generics vs. Inheritance (1)



Generics vs. Inheritance (2)



Beyond this lecture . . .

- Study the “Generic Parameters and the Iterator Pattern” Tutorial Videos.

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