Typing, State, Parameter Passing
Dynamic and Static Typing (EPL 4.1-4.4, VRH 2.8.3)
Explicit State and Parameter Passing (VRH 6.1-6.4.4)

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Data types
• A datatype is a set of values and an associated set of operations
• An abstract datatype is described by a set of operations
• These operations are the only thing that a user of the abstraction can assume
  • Examples:
    – Numbers, Records, Lists, ... (Oz basic data types)
    – Stacks, Dictionaries, ... (user-defined secure data types)

Types of typing
• Languages can be weakly typed
  – Internal representation of types can be manipulated by a program
    • e.g., a string in C is an array of characters ending in ‘\0’.

  • Strongly typed programming languages can be further subdivided into:
    – Dynamically typed languages
      • Variables can be bound to entities of any type, so in general the type is only known at run-time, e.g., Oz, SALSA.
    – Statically typed languages
      • Variable types are known at compile-time, e.g., C++, Java.

Type Checking and Inference
• Type checking is the process of ensuring a program is well-typed.
  • One strategy often used is abstract interpretation:
    • The principle of getting partial information about the answers from partial information about the inputs
    • Programmer supplies types of variables and type-checker deduces types of other expressions for consistency

  • Type inference frees programmers from annotating variable types: types are inferred from variable usage, e.g. ML.

Example: The identity function
• In a dynamically typed language, e.g., Oz, it is possible to write a generic function, such as the identity combinator:

  ```oz
  fun {Id X} X end
  ```

  • In a statically typed language, it is necessary to assign types to variables, e.g. in a statically typed variant of Oz you would write:

  ```oz
  fun {Id X:integer} integer X end
  ```

  These types are checked at compile-time to ensure the function is only passed proper arguments. `{Id 5}` is valid, while `{Id Id}` is not.

Example: Improper Operations
• In a dynamically typed language, it is possible to write an improper operation, such as passing a non-list as a parameter, e.g. in Oz:

  ```oz
  declare fun {ShiftRight L:List} L end
  ```

  • In a statically typed language, the same code would produce a type error, e.g. in a statically typed variant of Oz you would write:

  ```oz
  declare fun {ShiftRight L:List} L end
  ```

  • In a statically typed language, the same code would produce a type error, e.g. in a statically typed variant of Oz you would write:

  ```oz
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  • In a statically typed language, the same code would produce a type error, e.g. in a statically typed variant of Oz you would write:
Example: Type Inference

- In a statically typed language with type inference (e.g., ML), it is possible to write code without type annotations, e.g. using Oz syntax:

```oz
declare fun {Increment N} N+1 end
[Browse {Increment 4}] ! compiler error!!
[Browse {Increment 4}] ! proper use
```

- The type inference system knows the type of `+` to be:

```plaintext
<number> X <number> → <number>
```

Therefore, `Increment` must always receive an argument of type `<number>` and it always returns a value of type `<number>`.

Static Typing Advantages

- Static typing restricts valid programs (i.e., reduces language’s expressiveness) in return for:
  - Improving error-catch ability
  - Efficiency
  - Security
  - Partial program verification

Dynamic Typing Advantages

- Dynamic typing allows all syntactically legal programs to execute, providing for:
  - Faster prototyping (partial, incomplete programs can be tested)
  - Separate compilation—indeed written modules can more easily interact—which enables open software development
  - More expressiveness in language

Combining static and dynamic typing

- Programming language designers do not have to make an all-or-nothing decision on static vs dynamic typing.
  - e.g., Java has a root `Object` class which enables polymorphism
    - A variable declared to be an `Object` can hold an instance of any (non-primitive) class.
    - To enable static type-checking, programmers need to annotate expressions using these variables with casting operations, i.e., they instruct the type checker to pretend the type of the variable is different (more specific) than declared.
    - Run-time errors/exceptions can then occur if type conversion (casting) fails.
  - Alice (Saarland U.) is a statically-typed variant of Oz.

What is state?

- State is a sequence of values in time that contains the intermediate results of a desired computation
- Declarative programs can also have state according to this definition
- Consider the following program

```oz
fun {Sum Xs A} case Xs of X|Xr then {Sum Xr A+X} end end
[Browse {Sum [1 2 3 4] 0}]
```

What is implicit state?

The two arguments `Xs` and `A` represent an implicit state

```oz
fun {Sum Xs A} case Xs of X|Xr then {Sum Xr A+X} end end
[1 2 3 4] 0
[2 3 4] 1
[3 4] 3
[4] 6
nil 10

(Browse {Sum [1 2 3 4] 0})
```
What is explicit state?

- X = {NewCell I}
  - Creates a cell with initial value I
  - Binds X to the identity of the cell
- Example: X = {NewCell 0}
- {Assign X J}
  - Assumes X is bound to a cell C (otherwise exception)
  - Changes the content of C to become J
- Y = {Access X}
  - Assumes X is bound to a cell C (otherwise exception)
  - Binds Y to the value contained in C

Examples

- X = {NewCell 10}
  - Y = {NewCell 10}
  - X == Y % returns false
  - Because X and Y refer to different cells, with different identities
- {Access X} == {Access Y} returns true

The model extended with cells

Semantic stack

- w = f(x)
- z = person(a;y)
- y = α1
- u = α2
- α1: w
- α2: x
- single assignment store
- mutable store
The stateful model

```
{a} := skip                      empty statement
| {a_1} {a_2}                     statement sequence
| ...                             
| {NewCell (a) (c)}               cell creation 
| {Exchange (a) (c) (y)}          cell exchange
```

Exchange: bind \( (a) \) to the old content of \( (c) \) and set the content of the cell \( (c) \) to \( (y) \)

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Abstract data types (revisited)

- For a given functionality, there are many ways to package the ADT. We distinguish three axes.
- Open vs. secure ADT: is the internal representation visible to the program or hidden?
- Declarative vs. stateful ADT: does the ADT have encapsulated state or not?
- Bundled vs. unbundled ADT: is the data kept together with the operations or is it separable?
- Let us see what our stack ADT looks like with some of these possibilities

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Stack: Open, declarative, and unbundled

- Here is the basic stack, as we saw it before:

  ```
  fun {NewStack} nil end
  fun {Push S E} E|S end
  fun {Pop S E} case S of X|S1 then E=X S1 end end
  fun {IsEmpty S} S==nil end
  ```

- This is completely unprotected. Where is it useful? Primarily, in small programs in which expressiveness is more important than security.

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Stack: Secure, declarative, and unbundled

- We can make the declarative stack secure by using a wrapper:

  ```
  local Wrap Unwrap
  in
  {NewWrapper Wrap Unwrap}
  fun {NewStack} (Wrap nil) end
  fun {Push W X} E|{Wrap Unwrap S} end
  fun {Pop W X} case (Unwrap S) of X|S1 then E=X (Wrap S1) end end
  fun {IsEmpty S} (Unwrap S) ==nil end
  ```

- Where is this useful? In large programs where we want to protect the implementation of a declarative component.

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Stack: Secure, stateful, and unbundled

- Let us combine the wrapper with state:

  ```
  local Wrap Unwrap
  in
  {NewWrapper Wrap Unwrap}
  fun {NewStack} (Wrap (NewCell nil)) end
  fun {Push W X} C|{Unwrap W} in (Assign C X)(Access C) end
  fun {Pop W} C|{Unwrap W} in case (Access C) of X|S then (Assign C S) X end
  end
  fun {IsEmpty S} (Access (Unwrap W)) ==nil end
  ```

- This version is stateful but lets us store the stack separate from the operations. The same operations work on all stacks.

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Stack: Secure, stateful, and bundled

- This is the simplest way to make a secure stateful stack:
  ```plaintext
  proc {NewStack?Push?Pop?isEmpty}
  C={NewCell nil}
  in
  proc {Push X} {Assign C X| {Access C}} end
  fun {Pop} case {Access C} of X|S then {Assign C S} X end end
  fun {IsEmpty} {Access C}==nil end
  end
  ```
- Compare the declarative with the stateful versions: the declarative version needs two arguments per operation, the stateful version uses higher-order programming (instantiation)
- With some syntactic support, this is object-based programming

Four ways to package a stack

- Open, declarative, and unbundled: the usual declarative style, e.g., in Prolog and Scheme
- Secure, declarative, and unbundled: use wrappers to make the declarative style secure
- Secure, stateful, and unbundled: an interesting variation on the usual object-oriented style
- Secure, stateful, and bundled: the usual object-oriented style, e.g., in Smalltalk and Java
- Other possibilities: there are four more possibilities!

Exercise: Try to write all of them.

Parameter Passing Mechanisms

- Operations on data types have arguments and results. Many mechanisms exist to pass these arguments and results between calling programs and abstractions, e.g.:
  - Call by reference
  - Call by variable
  - Call by value
  - Call by value-result
  - Call by name
  - Call by need
- We will show examples in Pascal-like syntax, with semantics given in Oz language.

Call by reference

- `Call by reference`
- `Call by variable`
- `Call by value`
- `Call by value-result`
- `Call by name`
- `Call by need`
- The variable passed as an argument can be changed inside the procedure with visible effects outside after the call.
- The identity of the cell is passed to the procedure.
- The local cell is initialized with the argument of `Sqr`.
- The default mechanism in Oz is call by reference.

Call by variable

- `Call by variable`
- `Call by value`
- `Call by value-result`
- `Call by name`
- `Call by need`
- A value is passed to the procedure. Any changes to the value inside the procedure are purely local, and therefore, not visible outside.
- The local cell C is initialized with the argument A of `Sqr`.
- Java uses call by value for both primitive values and object references.
- SALSA uses call by value in both local and remote message sending.
Call by value-result

```plaintext
procedure sqr(input a:integer;
begin
  a := a*a
end
var
  i:integer;
end;

• A modification of call by variable. Variable argument can be modified.
• There are two mutable variables: one inside `sqr` (namely `a`) and one outside (namely `i`). Any intermediate changes to the variable inside the procedure are purely local, and therefore, not visible outside.
• `ivar` is ADA terminology.
```

Call by name

```plaintext
procedure callbyname a:integer;
begin
  a := a*a
end
var
  i:integer;
end;

• Call by name creates a function for each argument (a `thunk`). Calling the function evaluates and returns the argument. Each time the argument is needed inside the procedure, the thunk is called.
• Thunks were originally invented for Algol 60.
```

Call by need

```plaintext
procedure callbyneed a:integer;
begin
  a := a*a
end
var
  i:integer;
end;

• A modification of `call by name`. The thunk is evaluated at most once. The result is stored and used for subsequent evaluations.
• `Call by need` is the same as lazy evaluation. Haskell uses lazy evaluation.
• `Call by name` is lazy evaluation without memoization.
```

Which one is right or best?

```plaintext
• It can be argued that `call by reference` is the most primitive.
  - Indeed, we have coded different parameter passing styles using `call by reference` and a combination of calls and procedure values.
  - Arguably, `call by value` (along with cells and procedure values) is just as general. E.g., the example given for `call by variable` would also work in a `call by value` primitive mode: Exercise: Why?
• When designing a language, the question is: for which mechanism(s) to provide linguistic abstractions?
  - It largely depends on intended language use, e.g., `call by name` and `call by need` are integral to programming languages with lazy evaluation (e.g., Haskell and Miranda.)
  - For concurrent programs, `call by value-result` can be very useful (e.g. Ada.)
  - For distributed programs, `call by value` is best due to state encapsulation (e.g., SALSA.)
```

More parameter passing styles

```plaintext
• Some languages for distributed computing have support for `call-by-move`.
  - Arguments to remote procedure calls are temporarily migrated to the remote location for the time of the remote procedure execution (e.g., Emerald).
  - A dual approach is to migrate the object whose method is to be invoked to the client side before method invocation (e.g., Os).
• Java Remote Method Invocation (RMI) dynamically determines mechanism to use depending on argument types.
  - It uses `call by reference` in remote procedure calls, if and only if, arguments implement a special (Remote) interface
  - Otherwise, arguments are passed using `call by value`.
  - `⇒` Semantics of method invocation is different for local and remote method invocations!
• There is no language support for object migration in Java (as there is in other languages, e.g., SALSA, Os, Emerald), so `call by move` is not possible.
```

Exercises

84. VRH Exercise 6.10.2 (page 482).
85. Explain why `call by need` cannot always be emulated as shown in the given example by producing a counter-example. (Hint: recall the difference between normal order evaluation and applicative order evaluation in terms of lambda calculus expression evaluations.)
87. Create a program in which `call by name` and `call by need` parameter passing styles result in different outputs.
88. *Can type inference always deduce the type of an expression?*
  - If not, give a counter-example.
  - Arguably, `call by reference` (along with cells and procedure values) is just as general. E.g., the example given for `call by variable` would also work in a `call by value` primitive mode: Exercise: Why?
89. For concurrent programs, `call by value-result` can be very useful (e.g. Ada.)
90. For distributed programs, `call by value` is best due to state encapsulation (e.g., SALSA.)