Concepts of programming languages

Janus

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Janus

A reversible programming language.

Not turing complete!

Reversibility

Every statement can be reverted. No history is stored.

```
x += y * 3
```

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```
x -= y * 3
```

Injective functions

Reversible languages can only compute injective functions.

$$\forall x, y : f(x) = f(y) \implies x = y \tag{1}$$

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$$h(x) = (x, g(x)) \tag{2}$$

Turing completeness

Turing machines can compute non-injective functions.

Reversible languages are not turing complete.

Reversible Turing complete.

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Turing machines

Infinite tape of memory

Finite set of states

Transition function

- Current state
- Current symbol on tape
- Write symbol
- Move tape pointer
- Next state

Turing machines

Forward deterministic: given any state and tape, there is at most one transition *from* that state.

Backward deterministic: given any state and tape, there is at most one transition *to* that state.

P is the class of forward deterministic turing machines, NP of non-deterministic turing machines.

Reversible Turing complete: a language that can simulate forward and backward deterministic turing machines.

What do reversible languages compute

Given a forward deterministic turing machine that computes $f(x)$,

There exists a reversible turing machine that computes $x \to (x, f(x))$.

More memory.

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Motivation

What are reasons to pursue logically reversible computations?

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- More heat efficient circuitry
- Quantum computing

A small detour

Let's venture into the realm of physics:

Imagine a set of balls bouncing around in a frictionless world:

Bouncing balls 1

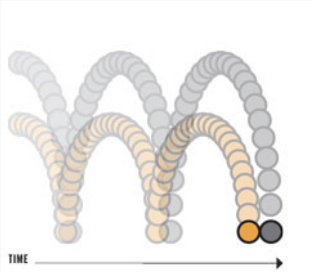

Figure 1: bouncing balls in a world without friction

Bouncing balls 1

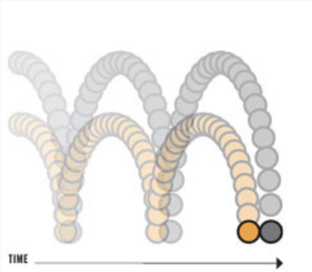

Figure 1: bouncing balls in a world without friction

All information about both future and past configurations is preserved.

Bouncing balls 2

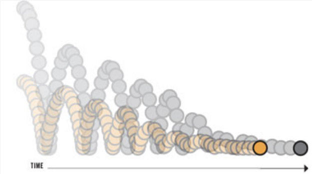

Figure 2: bouncing balls in the real world

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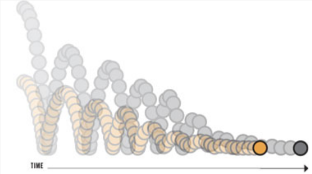

Figure 2: bouncing balls in the real world

Information about past configurations gets lost as the balls lose velocity.

This information is not truely lost, however.

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Entropy of the system must increase or remain equal. In this case, **heat** is dissipated into the environment.

Landauer's principle

In computers, information about past states is often lost (or erased) as computations are carried out.

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However, the second law of thermodynamics still applies.

This means that circuits *must* dissipate some amount of heat as information gets destroyed.

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Commonly refered to as **Landauer's principle**.

Reversible computing

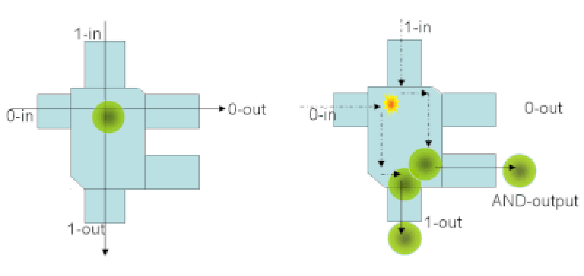

Figure 3: Billiard ball AND-gate

Reversible computing

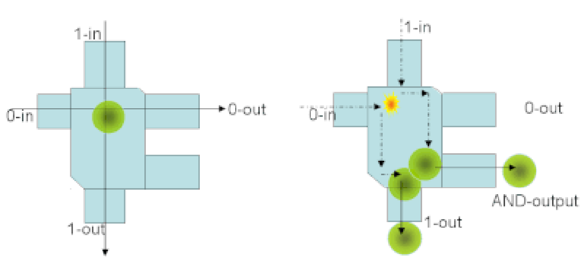

Figure 3: Billiard ball AND-gate

This is also refered to as a **Toffoli gate**.

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But ciruits with energy dissipation below the von Neumann-Landauer limit have been built.

Quantum Computing

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The underlying physical processes of quantum computing are actually fundamentally reversible.

Similar to the frictionless billiard ball gate, information cannot leave a quantum circuit in the form of heat.

The system is said to be **locigally reversible**.

Logical reversiblity

Since all logical information is preserved in such systems, it is imposible to carry out certain computations.

Specifically, it is impossible to carry out computations that reach a logical state that can also be reached through other paths of computation.

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Notice the similarity with reversible Turing machines!

Variables

- All global variables
- Default value
- Modification operators
- Only support for `+=`, `-=` and `^=`

Limitations

- There is no `*=` and `/=`
- A variable that occurs on the left can not occur on the right in the same statement
  - `x-=x` is forbidden

```
a b c

procedure main
    a += 3
    b -= a + 4
    c += a - b
```

Procedures

- No parameters
- There exists a version with parameters
- Pass by reference

```
a
procedure main
    call f
    uncall g

procedure f
    a += 3

procedure g
    a -= 5
    a += 1
```

Loop

```
from e1 do
    s1
loop
    s2
until e2
```

- `e1` is true only the first iteration, false every other iteration
- `s1` is executed after `e1` on every iteration
- `e2` is false until the last run
- `s2` is executed if `e2` is true, continue to `e1`

Loop

```
a
b

procedure main
    from a = 0 do
        a += 1
    loop
        b += a
    until a = 10
```

The result is `{ a = 10, b = 45 }`

Example

`fib`: calculates (n+1)-th and (n+2)-th Fibonacci number.

```
procedure fib
    if n = 0 then
        x1 += 1    ; -- 1st Fib nr is 1.
        x2 += 1    ; -- 2nd Fib nr is 1.
    else
        n -= 1
        call fib
        x1 += x2
        x1 <=> x2
    fi x1 = x2
```

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- Q: How do we calculate the inverse?

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        call fib
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        x1 <=> x2
    fi x1 = x2      ; -- Used for inverting the if-statement.
```

$$\mathcal{I}[\![\texttt{if } e_1 \texttt{ then } s_1 \texttt{ else } s_2 \texttt{ fi } e_2]\!] \quad = \texttt{if } e_2 \texttt{ then } \mathcal{I}[\![s_1]\!] \texttt{ else } \mathcal{I}[\![s_2]\!] \texttt{ fi } e_1$$

Example

`fib`: calculates (n+1)-th and (n+2)-th Fibonacci number.

```
procedure fibInverse
    if x1 = x2 then
        x2 -= 1          ; -- 2nd Fib nr is 1.
        x1 -= 1          ; -- 1st Fib nr is 1.
    else
        x1 <=> x2
        x1 -= x2
        call fibInverse
        n += 1
    fi n = 0
```

Example

`fib`: calculates (n+1)-th and (n+2)-th Fibonacci number.

- Q: What does the inverse of fib do?

```
procedure fibInverse
    if x1 = x2 then
        x2 -= 1           ; -- 2nd Fib nr is 1.
        x1 -= 1           ; -- 1st Fib nr is 1.
    else
        x1 <=> x2
        x1 -= x2
        call fibInverse
        n += 1
    fi n = 0
```

Relational Programming

Injective Programming	**Relational Programming**
r-Turing Complete	Turing Complete
backwards deterministic	backwards non-deterministic
restricted language constructs	search procedure (aka *resolution*)

Prolog basics

A logic program consists of *facts* and *rules*.

```
parent(alice, joe).
parent(bob, joe).
parent(joe, mary).
parent(gloria, mary).

ancestor(X, Y) :- parent(X, Y).
ancestor(X, Y) :- parent(X, Z), ancestor(Z, Y).

descendant(X, Y) :- ancestor(Y, X).
```

The user can then *query* the runtime system, as such:

```
?- ancestor(alice, mary).
true.

?- parent(X, mary).
X = joe;
X = gloria.

?- ancestor(X, mary), not parent(X, mary).
X = alice;
X = bob.
```

Demonstration - Type Predicate

Assume a `type` predicate, relating expressions with types:

```
type(expr, t) :- ... .
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You would normally use it to perform *type-checking*:

```
?- type(1 + 1, int).
true.
?- type(1 + 1, string).
false.
```

But you can also perform *type-inference*:

```
?- type(1 + 1, Type).
Type = int.
?- type("hello world", Type).
Type = string.
?- type(λx:int -> x, Type).
Type = int -> int.
?- type(λx -> x, int -> Type).
Type = int.
```

Going in the reverse direction, you can generate programs:

```
?- type(Expr, int).
Expr = 1;
Expr = 2;
...
Expr = 1 + 1;
Expr = 1 + 2;
...
Expr = if true then 1 else 1;
...
```

Of course, this does not make much sense without a sufficiently expressive type system.

Demonstration - Relational Interpreter

Assume you have implemented a *relational interpreter*:

```
eval(program, result) :- ... .

?- eval(map (+ 1) [1 2 3], Result).
Result = [2 3 4].
```

Demonstration - Relational Interpreter

Assume you have implemented a *relational interpreter*:

```
eval(program, result) :- ... .

?- eval(map (+ 1) [1 2 3], Result).
Result = [2 3 4].
```

Non-deterministic constructs are also natural:

```
?- eval(amb [a, b, c], Result).
Result = a;
Result = b;
Result = c.
```

But you can also perform *program synthesis* by-example:

```
?- eval(F 1, 2),...,eval(map F [1 2 3], [2 3 4]).
...
F = λx -> x + 1;
...
F = λx -> x - 10 + 10 + 1;
...
```

But you can also perform *program synthesis* by-example:

```
?- eval(F 1, 2),...,eval(map F [1 2 3], [2 3 4]).
...
F = λx -> x + 1;
...
F = λx -> x - 10 + 10 + 1;
...
```

Quine generation is straightforward:

```
?- eval(Quine, Quine).
...
Quine = (λa -> a ++ show a) "(λa -> a ++ show a) ";
...
```

Logic Programming IRL

In practice, bi-directionality breaks with the usage of *extra-logical* features:

- **Variable projection**: inspecting values at runtime
- **Cut (!)**: disables backtracking in certain places
- **Assert/Retract**: dynamically insert/remove facts

Logic Programming IRL

In practice, bi-directionality breaks with the usage of *extra-logical* features:

- **Variable projection**: inspecting values at runtime
- **Cut (!)**: disables backtracking in certain places
- **Assert/Retract**: dynamically insert/remove facts

MiniKanren is a more recent logic programming language, which avoids extra-logical features (as much as possible).

Higher abstraction

- Relational programming, as well as functional programming, both belong to the *declarative* paradigm.
- They both focus on *what* a program does, rather than *how*.

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Question

How can we combine them, to get the best of both worlds?

Hanus: Janus embedded in Haskell

In our research project, we use *TemplateHaskell* and *QuasiQuotation* to embed Janus in Haskell:

```
[hanus| procedure encode(im :: Image, ret :: [Byte]) {
    -- Janus commands with antiquotation
}|]
encode :: Image -> [Byte]
encode = call encode
decode :: [Byte] -> Image
decode = uncall encode
```

Come and check out our poster in de Vagant!

Thanks! Questions?

From CodeComics.com, modified.

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References

Axelsen, Holger Bock, and Robert Glück. “What do reversible programs compute?.” FoSSaCS. 2011. Yokoyama, Tetsuo, and Robert Glück. “A reversible programming language and its invertible self-interpreter.” Proceedings of the 2007 ACM SIGPLAN symposium on Partial evaluation and semantics-based program manipulation. ACM, 2007.