Casanova 2.0

Doing nothing with style

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Agenda

1. A short history of computing
2. The non-halting problem
3. The Casanova language for game development

A short history of computing

Original goals

- Questions about automation of mathematical tasks
- Automated procedures to compute algorithm results
- Automated procedures to prove theorems

A short history of computing

First tools

- A series of theoretical (and later physical) machines
- Turing machine [10]
- λ-calculus (Alonzo Church) [1]
- μ-recursive functions [7]
- ...

Turing machine

First tools

- A tape of cells; each cell has a symbol
- A head that can read and write symbols on the tape and move the tape left and right by one
- A state register that stores the state of the Turing machine, one of finitely many
- A table of instructions that, given the state the machine is currently in and the symbol it is reading on the tape tells the machine to do the following in sequence:
  - Either erase or write a symbol
  - Move the head (`L`, `N`, `R`)
  - Change the state

λ-calculus

First tools

- Three grammatical elements:
  - `x`
  - `t s`
  - λ `x.t`

λ-calculus

First tools

- Three grammatical elements:
  - `x`
  - `t s`
  - λ `x.t`
- β reduction:
  - (λ `x.t`) `s` reduces to `t[x` $\rightarrow$ `s]`

A short history of computing

Expressive power

- First question was *how powerful are these things?*
- Second question was *is any of those more powerful than the others?*

A short history of computing

Expressive power

- First question was *how powerful are these things?*
- Second question was *is any of those more powerful than the others?*
- All computational processes (recursion, the λ-calculus, and the Turing machine) are **equivalent** [4]

A short history of computing

Expressive power and the Turing-Church thesis

- Hypothesis about *effectively calculable* functions [4]
- Functions are *effectively calculable* when computable by a Turing machine
- Computability $\equiv$ those three equivalent processes

A short history of computing

Expressive power and the Turing-Church thesis

- Hypothesis about *effectively calculable* functions [4]
- Functions are *effectively calculable* when computable by a Turing machine
- Computability $\equiv$ those three equivalent processes
- Further research: real computer $\equiv$ Turing machine
  - Any type of subroutine
  - Recursive procedures
  - Any of the known parameter-passing mechanisms
- *Disregarding IO*[a]

[a] we will get back to this

A short history of computing

Core focus

Disregarding IO
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Disregarding IO
Disregarding IO
...

A short history of computing

Core focus

- Goal of programs was to:
  - Compute results
  - Go straight from *question* (input) to *answer* (output)
- This led to lots of effort towards ensuring *termination of programs*
  - A program that loops forever is clearly *stuck*
  - Unambiguously considered not useful: will never produce an answer

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Termination and IO

- Termination is, yet today, a fundamental property of computation
- *will my X terminate?*:
  - SQL query
  - Web-page rendering
  - Path-finding algorithm
  - Image processing
  - ...

A short history of computing

Halting problem

"Given a description of an arbitrary computer program, decide whether the program finishes running or continues to run forever". [9]

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Halting problem

- Turing proved in 1936 that a general algorithm to solve the halting problem for all possible program-input pairs cannot exist
- The halting problem is undecidable over Turing machines

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Halting problem

- Static analysis techniques to approximately determine termination
  - Type systems [2]
  - Model checking [6]
  - Abstract interpretation [3]
  - Complexity analysis (Big-O notation)
  - ...

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Halting problem

- There even exist languages that only produce terminating programs
  - SQL
  - Shaders
  - ...
- They are not Turing-equivalent
- If we lose the ability to not-terminate, we lose lots of expressive power

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Simply-typed λ-calculus

- Terms have types: $\frac{t:a \rightarrow b,\ u:a}{t\ \ u:b}$
- Every application of β-reduction strictly reduces the type complexity of the term
- *Strongly-normalizing*: well-typed terms always reduce to a value
- Impossible to define looping terms or anything that requires complex recursion/iteration
    - Parsing (even on regular expressions)
    - The Ackermann function
    - ...

The non-halting problem

Always doing something?

- Most programming languages only deal with termination
- `Do-something` operations
- Always take a step towards the final goal
- Abuse the language to do nothing
  - `while C do x += 0;`

The non-halting problem

The non-halting problem

- Termination sometimes makes no sense
  - OS
  - Games
  - ...
- Anything interactive where *IO determines when we are done*

The non-halting problem

Interaction and non-termination

- Show information at a human pace (much slower than computer ability to generate it)
- Wait for human to be ready or to express desire to interact
- **Example**

The non-halting problem

Doing nothing with style :)

- Games and other non-terminating applications need the ability to **selectively do nothing**
- Some entities/parts of the world/sub-systems/sub-algorithms are just **waiting**
  - For time to pass
  - For input
  - For specific conditions in the game world
  - For *complex combinations* of the above

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Our goal

Design a programming language[a] where *time is a first-class primitive*. [8]

[a] centred around computer games

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Time, data, and computations

- Move from handling *data and computations* to handling *data, computations, and the flow of time*
- Implicit concept of the *uninterruptible flow of time* (the main loop)
- Automated updates of entities through first class transformation operations (`rule`)
- `wait`/`when` as a first-class concept

Simple ball dynamics

```
world Ball = {
  S : Sprite
  P : Vector2<m>
  V : Vector2<m/s>
  G : Vector2<m/s^2>
  rule P = yield P + dt * V
  rule V = yield V + dt * G
}
```

Syntax

```
<Program> ::= <worldDecl> {<entityDecl>}

<worldDecl>  ::= world id = <entityBody>
<entityDecl> ::= entity id = <entityBody>
<entityBody> ::= "{" {<fieldDecl>} {<ruleDecl>} "}"

<fieldDecl>  ::= id ":" <type>
<ruleDecl>   ::= rule id {"," id} "=" <expr>
<type>       ::= int | float | Vector2 | ...

<expr > ::= ...(* typical expressions : let , if ,
                  for , while , etc. *)
           | <queryExpr > | "wait" <expr> | "yield" <
              expr>
           | <arithExpr > | <boolExpr > | <literal>
```

Semantics

```
E = { Field_1 = f_1; ...; Field_n = f_n
      Rule_1 = r_1; ...; Rule_m = r_m }

tick(e:E, dt) =
 { E with Field_1=tick(f_1^m, dt); ...; Field_n=tick(f_n^m, dt)
      ;
          Rule_1=r'_1; ...; Rule_m=r'_m }

where
   f_1^m, ..., f_n^m, r'_m = step(f_1^(m-1), ..., f_n^(m-1), r_m)
   ⋮
   f_1^2, ..., f_n^2, r'_2 = step(f_1^1, ..., f_n^1, r_2)
   f_1^1, ..., f_n^1, r'_1 = step(f_1, ..., f_n, r_1)
```

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A "small" challenge

A light-switch.[a]

[a] Serious kudos to Dino Dini for the idea.

An empty slide for you guys to think :)

Simple light-switch

```
world LightSwitch = {
  S : Sprite
  P : bool
  rule P =
    when(IsKeyDown(Keys.Space))
    yield true
    yield false
    when(IsKeyUp(Keys.Space))
  rule S.Color =
    yield Color.White
    when P
    yield Color.Black
    when P
}
```

Three state light-switch

```
world LightSwitch = {
  S : Sprite
  P : bool
  rule P = ...
  rule S.Color =
    yield Color.Green
    when P
    yield Color.Orange
    when P
    yield Color.Red
    when P
}
```

Timed-on/off lightswitch

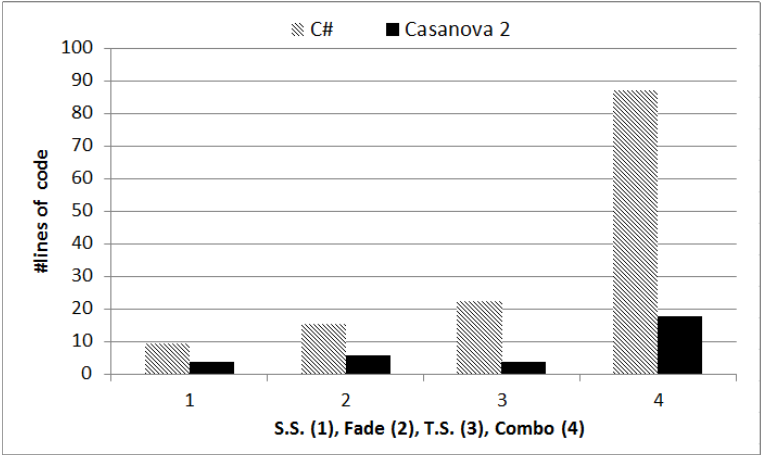
```
world LightSwitch = {
  S : Sprite
  rule S.Color =
    yield Color.Green
    wait 2.0f<s>
    yield Color.Orange
    wait 1.0f<s>
    yield Color.Red
    wait 3.0f<s>
}
```

Lightswitch in C#

```
public class FlatStateMachine : MonoBehaviour {
  bool state;
  bool previousInput;

  void Update () {
    bool currentInput = Input.GetMouseButton(0);
    if (!previousInput && currentInput) {
      state = !state;
      renderer.material.color = state ? new Color(0,
          0, 0) : new Color(1, 1, 1);
    }
    previousInput = currentInput;
  }
}
```

Comparison with C#



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Readability

- Programming languages are description tools
- Their main goal is to *tell another human what the machine should do* [5]
- Assessing the *readability of a language* is crucial

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Readability

- Test: students[a] read Casanova sources

Table: Feedback from students

Syntax is unfamiliar at first	3
Syntax is clear	8
Indentation instead of parentheses is a downside	2
List processing with queries is very effective	1
Rules are a good abstraction for games	2

[a] Games students, programming and design

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Compiler structure

- Parse
- Analyse and optimize queries
- Analyse and optimize `waits` with state machines
    - Event-system
    - Large `switch`-statement for each state machine
- Generate main loop
- Generate code
    - Using the C# syntax tree and Roslyn
    - Can also output C# instead of binaries

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Usage in practice

- All nice and all, but does it work in reality?

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Usage in practice

- All nice and all, but does it work in reality?
- Yup
- DEMO (RTS game)

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Future endeavours

Networking in games

Networking

<pre>local{
  rule X =
    send(b)
    if b then
      yield receive()
    else
      wait 1.0f<s>
      send(c)
}</pre>
	<pre>remote{
	  rule X =
	    let b = receive()
	    if b then
	      wait 1.0f<s>
	      send(c)
	    else
	      yield receive()
	}</pre>

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Conclusions

- Interaction negates termination, at least globally
- Modern programming languages suffer from this
- Need for better languages that handle time
- Concept of "do nothing" at the language level
  - High expressive power
  - Clean code
  - We argue results in a more pleasant "game development experience"

That's it

Thank you!

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