COMP0020: Functional Programming

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University College London

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Course Objective

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- Explores the functional programming paradigm and the implementation technology for functional programming languages.
- Uses the functional language "Miranda".

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NB : this module **does not aim to teach Haskell** (though we may discuss Haskell in passing).

Student Objectives

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1. Understand the basics of the lambda calculus and combinators and how they are used in the implementation of functional languages.
2. Understand the main features of a lazy functional language.

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3. Understand type checking, type-inference and the operation of the Hindley-Milner type system as implemented in Miranda.
4. Write, understand and analyse non-trivial functional programs in Miranda.

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5. Understand the computation and memory management issues affecting the sequential implementation of lazy functional languages.
6. Solve problems relating to all of the above, under examination conditions.

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Students are expected to improve their functional programming skills through independent study.

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In the second half of the course students are expected to use independent study to **read extensively** about implementation issues, which are then discussed in the lectures.

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Approximate Schedule of Lectures

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Tuesdays :	10am	Bentham House LG26 Lecture Room
Wednesdays :	10am	Bentham House LG26 Lecture Room
Fridays :	1pm	Cruciform Building B404 - LT2

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Start of Term :	Monday 13th January 2020
5 weeks of lectures :	Lambda Calculus, Miranda Programming, Advanced Concepts
(Reading Week)	
4-5 weeks of lectures :	Advanced Concepts, Implementation Techniques

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Moodle page : **COMP0020 : Functional Programming** (previously COMP3011COMPGC16) — essential reading !

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There is no marked coursework, but students must complete formative exercises during and between lectures. The book and the Moodle page have simple self-study exercises and answers. There are many past paper questions, without answers. Feedback is given on attempted solutions to past paper questions.

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Introduction to Functional Programming

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Many people think of Alan Turing as 'the father of computing", but there are many other important figures in computer science. In particular, Alonzo Church (Turing's PhD supervisor).

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Church and Turing promoted two different (and provably equivalent) approaches to programming :

- Turing was interested in building machines and understanding how to control them using a small set of rules.
- Church was interested in how to express problems in a precise way, to be solved by automatic transformation using a small set of rules.

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These approaches have much in common, but they lead to two radically different styles of programming.

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Consider the notion of programming languages in general :

- How many programming languages currently exist ?[1] and how many can you use ?
- Does the choice of language matter ?
- Are older programming languages irrelevant ?
  - should we only use the most recent language ?
  - are the rest just "junk" ?

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1. See "The next 700 programming laguages", P.J.Landin, 1965 at https ://homepages.inf.ed.ac.uk/wadler/papers/papers-we-love/landin-next-700.pdf

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- Can you just use (say) Java for every programming task ?
  - if a language (and associated compiler and runtime system) provides a computational system that is Turing-equivalent,[2] is it the only language you need to learn ?
  - Since many problems can be solved without the full power of a Turing Machine, why should we care ?

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- What else do programming languages gives us ? expressivity (e.g. type systems), abstraction, protection from common errors (e.g. type systems), different ways to think about solving problems
- Different languages, different computational models, **change the way we think**

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2. Turing-equivalence and Turing-completeness are outside the scope of this module.

- It can be helpful to group programming languages into different categories (though it can be difficult to do this precisely, since some languages incorporate more than one computational model).

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- There are many ways to do this ; one way is to identify

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  - the "imperative" languages (typically based on the concept of giving instructions to a machine)
    - e.g. Java, C++, Fortran
  - the "declarative" languages (typically based on the concept of solving a problem)
    - e.g. Haskell, Miranda, Prolog

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- The class of "declarative" languages contains both "functional" languages (e.g. based on Church's λ-calculus) and "logic" languages (e.g. based on first-order predicate calculus)

A simple example of the difference in programming style

- Assume "results" is the name of a variable that contains a sequence of 100 integers, and write code to select all those with a value less than 10
- Imperative style :

```
int      small[100];
int      j,k;
for      (j = 0, k = 0; j < 100; j++)
           if (results[j] < 10){ small[k] = results[j]; k++; }
return   (small);
```

- Functional style :

filter (< 10) *results*

  - Concise, low syntactic "clutter", reduced need to specify storage of intermediate results

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An example of literate programming style using Miranda

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Thus for any single phase m and component i,

$$\zeta_{m,i} = \frac{\xi_i}{\sum\limits_{r \in phases} s_r K_i^{r,m}} \tag{9.7}$$

```
> zeta m i k xi phases s =
>     xi i / sum [s r * k r m i | r <- phases]
```

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We can now derive a partial derivative for ζ with respect to s. This will be useful later when we construct and then solve some residual functions.

$$\frac{\partial \zeta_{m,i}}{\partial s_n} = -\frac{\xi_i \sum\limits_{r \in phases} \frac{\partial s_r}{\partial s_n} K_i^{r,m}}{\left(\sum\limits_{r \in phases} s_r K_i^{r,m} \right)^2} \tag{9.8}$$

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$$\frac{\partial \zeta_{m,i}}{\partial s_n} = -\zeta_{m,i} \frac{\sum\limits_{r \in phases} \frac{\partial s_r}{\partial s_n} K_i^{r,m}}{\sum\limits_{r \in phases} s_r K_i^{r,m}} \tag{9.9}$$

```
> dzeta_ds m i n k xi dep_phase phases s =
>     neg (zeta m i k xi phases s)
>     * sum [ds_ds r n dep_phase * k r m i | r <- phases]
```

A practical example of functional programming style

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- Functional Programming languages are renowned for their "elegance"

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  - But are they like Japanese Haiku poetry (elegant, but not very practical)?

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  - Or are they like Karate (elegant, and useful in a fight)?

- Prototyping a large object-oriented design using a functional programming language
  - A commercial project (a very large international settlement bank)
  - The world's largest IT Consultancy
  - A "mission-critical" financial system
  - Over 100 programmers
  - C++ required by client

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Component-based system design : a network of components (“nodes”) communicating via streams of data (”arcs”). One or more inputs (“arcs”), one output (“arc”).

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- Project requirements :
  - Discrete-event simulation of component network

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  - Prototyping of central optimisation and approximation algorithms
  - The main constraint was C++

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    - Too slow for rapid prototyping work (execution speed was very fast, but development time and debugging effort too great for prototyping many different designs)

- IT Consultancy's dilemma :
  - C++ required by client, but "not viable" for prototyping/simulation
    - ★ Would take too long to develop the underlying components
  - Rapid prototyping object-oriented language (e.g. Smalltalk) "not desirable"
    - ★ Smalltalk known to client — raised issue of suitability of client's choice of C++ (consultancy did not wish to "insult" client)
- Alternative approach — use a functional language (Miranda)
  - Higher Order, Statically Typed, Lazy, with Garbage Collection, no pointers, no assignment
  - Unknown to client (!)

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- Selling points :
  - Speed and Clarity with which algorithms can be
    - expressed
    - validated
  - Can simulate key object-oriented designs in detail
    - With minimal detail for other components!
- Access to expertise :
  - A "champion"

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- Note : Speed of execution was almost totally irrelevant !

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Modelling the component network

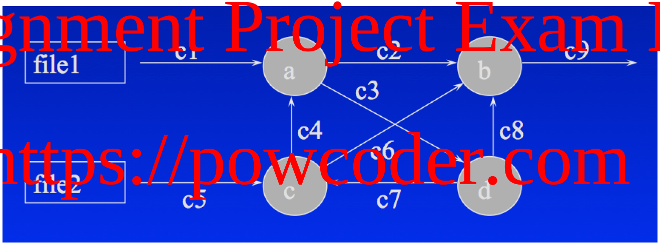

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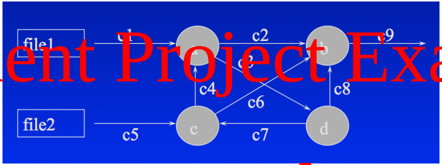
FIGURE : A network of component (nodes) sending streams of data (arcs) to each other.

- Recursive (looping) functions a, b, c and d
- c1, c2 etc. are streams of (time, value) events — represented by potentially-infinite lists of 2-tuples



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- Assume recursive (looping) functions a, b, c and d are defined elsewhere
- Define the streams of (time, value) tuple :

$$
\begin{aligned}
c1 &= read\ \text{"}file1\text{"}\\
c5 &= read\ \text{"}file2\text{"}\\
c9 &= b(c2, c6, c8)\\
(c2, c3) &= a(c1, c4)\\
(c4, c6) &= c(c5, c7)\\
(c7, c8) &= d(c3)
\end{aligned}
$$

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- Simulating behaviour
  - Simple, behavioural and *executable* specification
  - Expression-based (ordering of sub-expressions is easier than ordering of commands)
- Synthetic (statistical) data generation
- Used Miranda algorithms as specification for subsequent implementation in C++

Results

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- Rapid development
  - About 5 times faster than C++

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- Concise expression
  - 6 pages of Miranda = about 25 pages of C++

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- Simulation and specification of complex processes
  - Design optimised early in lifecycle
  - Confidence increased through validation on real data

Results

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- Almost NO errors in prototype code

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- Vast reduction in errors in final C++ code
- Viewed as a commercial advantage

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- Promoted worldwide within the IT Consultancy — "champion" promoted to Manager

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END OF LECTURE

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