# Functional Programming in Embedded System Design

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# Hard Real Time Embedded Systems MUST:

- Be highly Dependable.  Zero failures.
- Do what they're supposed to do.
- Not ever crash.
- Integrate complex hardware and software.
- Ensure behavior by some means before they are run.

# What Designers Want

- No run time exceptions:
  - No null pointers.
  - No out of range arrays.
  - No class casts.
  - No arithmetic exceptions - most difficult.
- Well specified execution semantics.
- No distinction between hardware and software.
- Implicit parallelism.
- Compatibility with existing languages if possible.

# Look to the Basics of Computer Science

- Functional Programming. Examples: Haskell and pH.
- Build execution semantics into the language.
  - Cycle based execution from sampling theory and synchronous computing.
  - Set the cycle rate based on input data streams.
  - Leads to synthesizable Verilog subset and synchronous dataflow graphs.
- Must be a net-list language so that we can map a program to one or more processors or to hardware.

# Take Out the Garbage

- All instantiation at initialization.
- After instantiation
  - Software: the program runs in a cyclical loop at a fixed rate (or set of rates) on one or more processors.
  - Hardware: the design is mapped to RTL(Verilog).
- The design is statically analyzable before being run.
- Analyzable side effects.

# Why Not Just Haskell?

- Layout syntax is not industrial strength.
- No clear treatment of memory and state.
- Input/Output?
- Object oriented design?
  - Inheritance.
  - Types and Type Classes.

# Introduce a Special Memory Function

- A “register” sources and/or sinks data each cycle.
- Single assignment rules:
  - Write once in a cycle. New value updated at the end of cycle.
  - Multiple reads during a cycle(old value only).
- Synchronous, unblocked reads and writes.
- Registers are instantiated only at initialization.
- Input and Output are memory mapped to Registers.

# Execution Cycle

- Fetch data from each input and from registers and place it at the input to all functions.
- Execute all functions.
- Not lazy evaluation.
- Store the produced values away in the appropriate registers.
- Conventional “drivers” must then fill and empty these registers outside the functional program.

# What if the Input Data rates vary widely?

- No interrupts.
- Multiple “Tasks” each cycle at a different rate.
- Inter-task communication by rate adapting filters.
- System model is locally synchronous and globally asynchronous.

# System Modeling with Finite State Machines

- Each Task can be represented as a Finite State Machine.
- The State is contained in the registers of each task.
- State changes only at an execution cycle boundary.
- Leads to a design model of concurrent FSM's.

# Software Implementation on a Stack

- The compiler converts C-like expressions to postfix.
- Execute the postfix directly on a simple stack machine.
- Is this Forth?  Almost!
  - No user written postfix.
  - Strongly typed (like Haskell).
- Stack machines are small, efficient and a target for soft cores in an FPGA.

# Hardware Implementation

- The front end of the compiler is the same!
- Only difference is that for hardware, the "interpreter" unwinds the postfix code into structural Verilog.
- Can we do without synthesis?
- For parallel processing, a complex mapping problem remains.

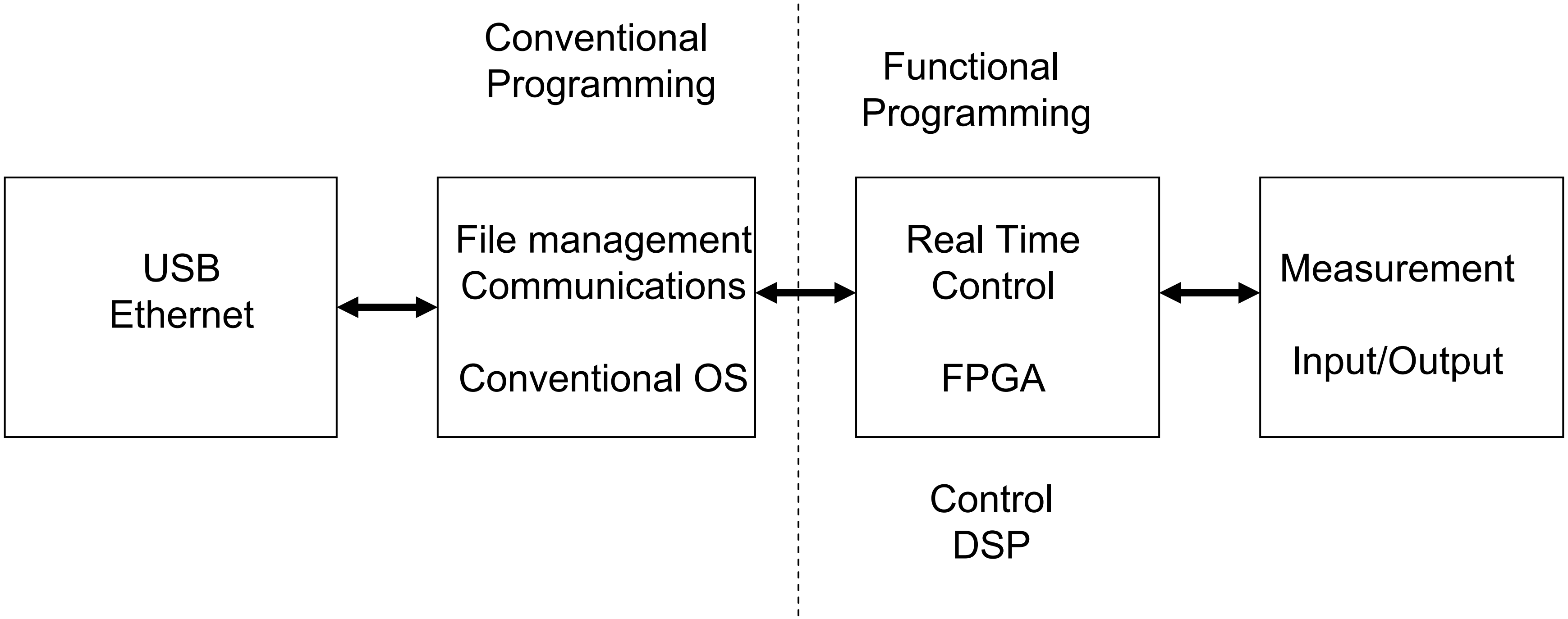
# Types and Type Classes

- Type Classes:
  - Members can be sub TypeClasses or Types
  - Abstract, not instantiated.
  - Lists methods that must be supplied by its Types.
- Types:
  - Are Instantiated.
  - Supply constructor and methods required by its Type Class.
- Sub-types differentiate with relations on property values of types.

# Polymorphism and Inheritance

- Simple tree like single inheritance.
- Parametric polymorphism.
- No class casts.
- Simplified form of Object Oriented Design.

# Partitioning an Embedded Architecture




Separate Soft from Hard Real Time Measurement and Control

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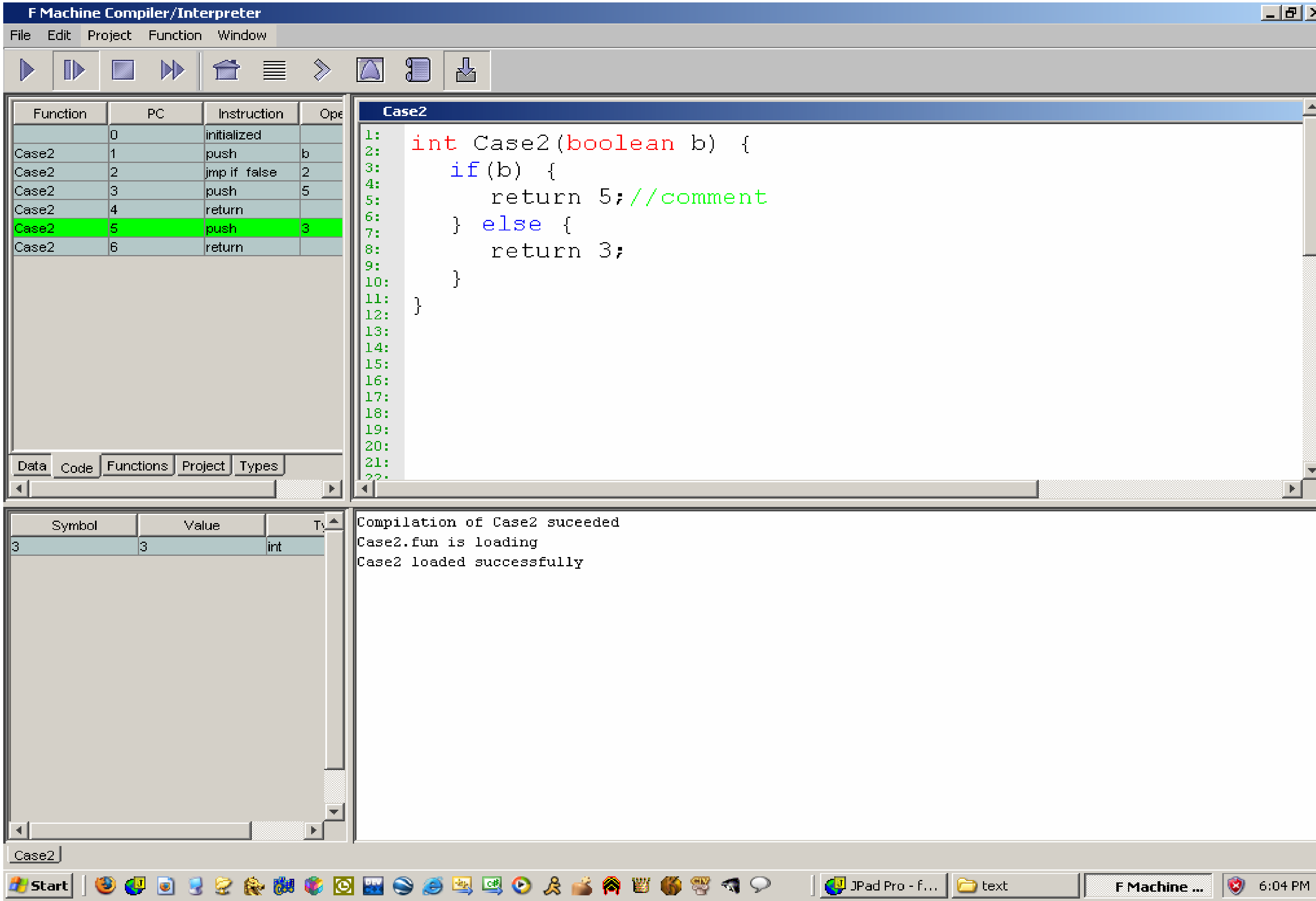
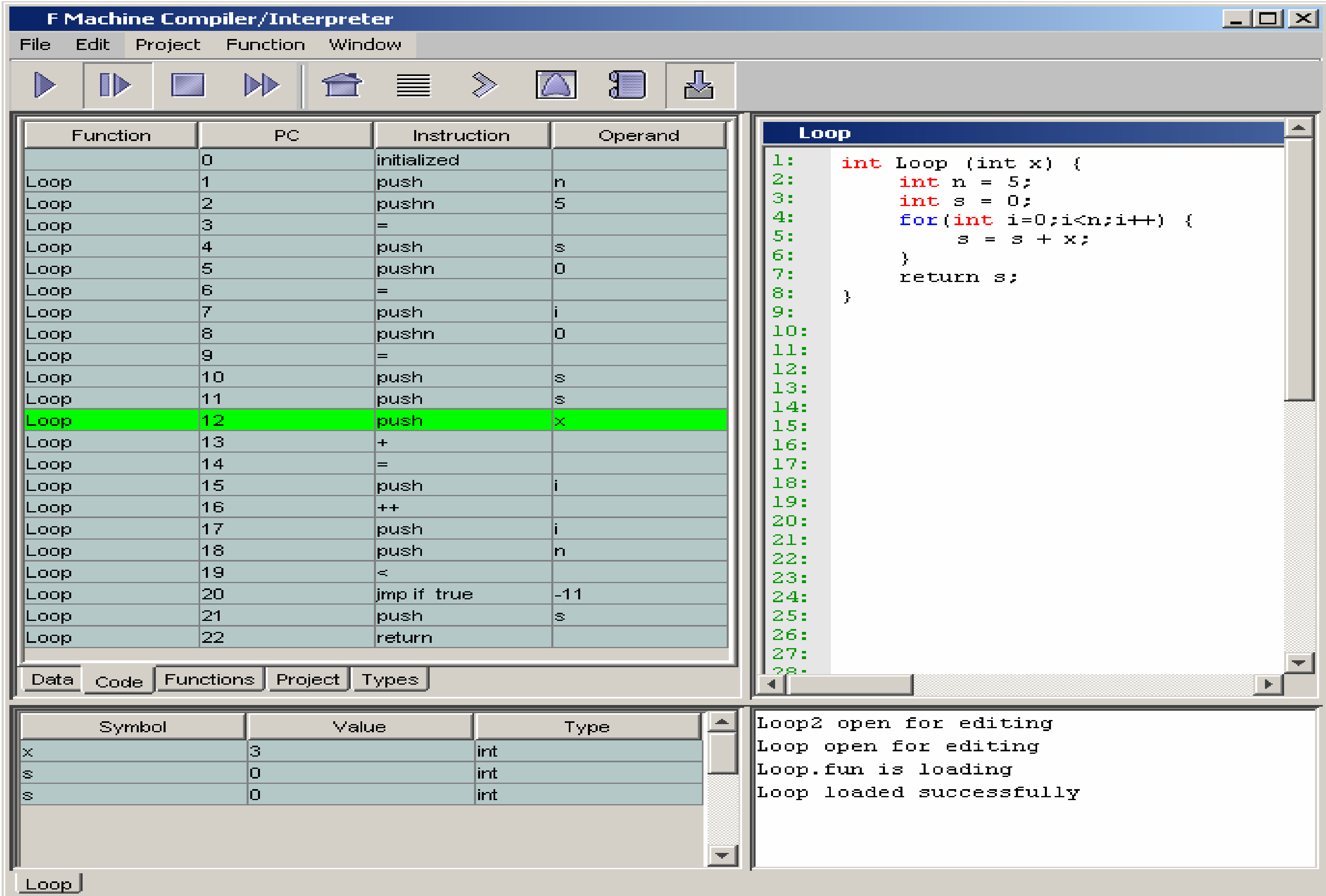
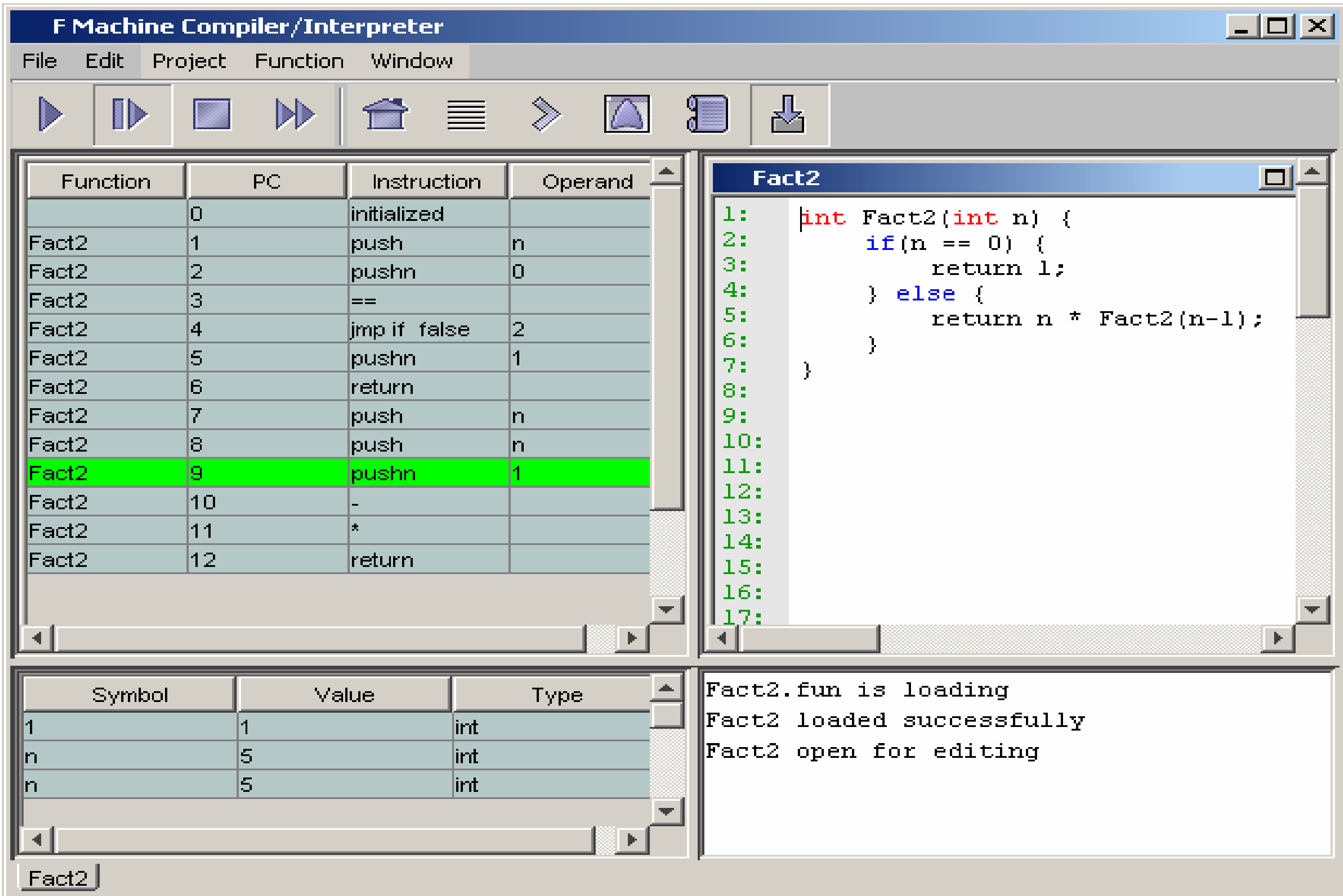


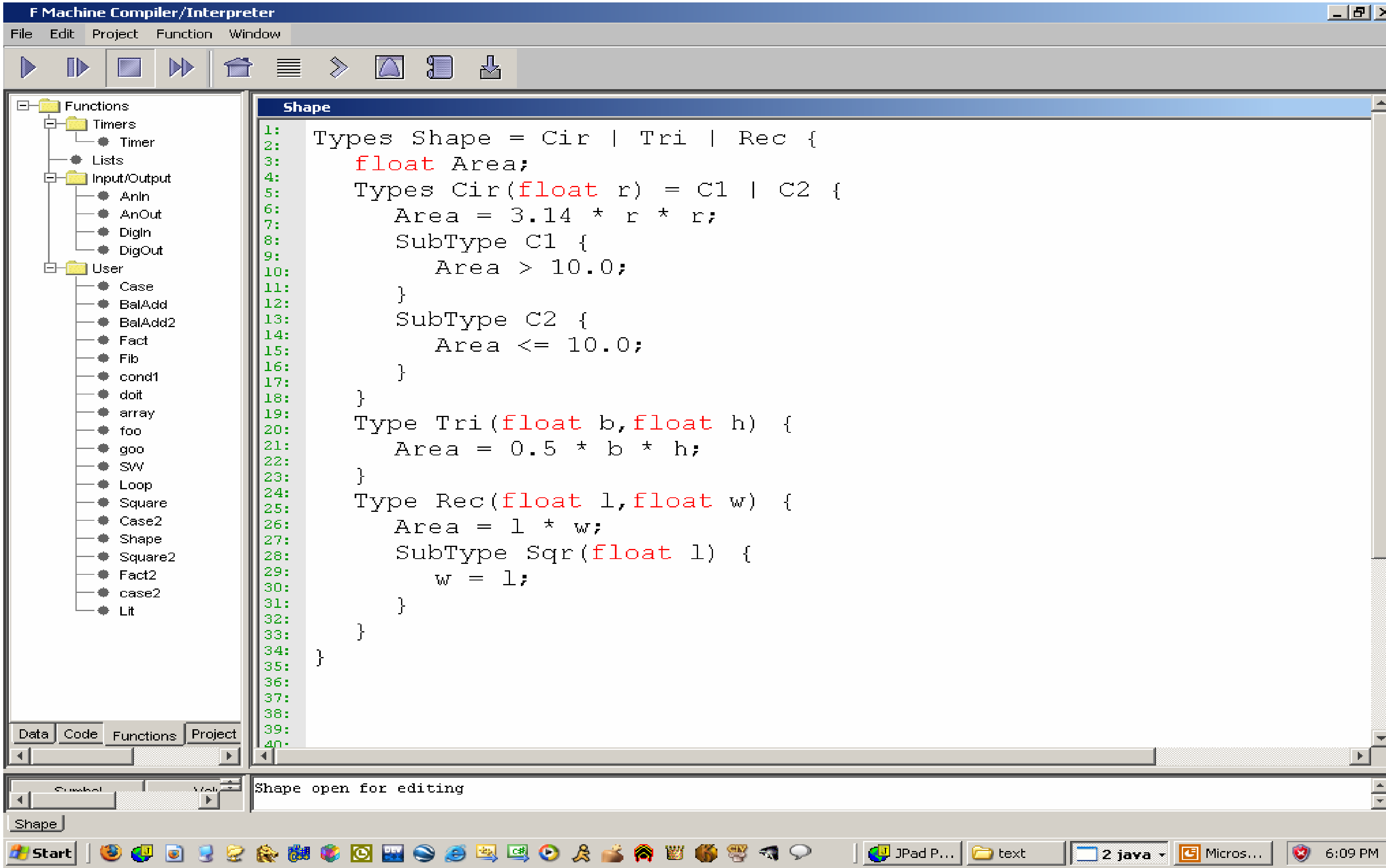

A Simple if – else branch executing. The return value is on the stack.




A “for” loop looks just like C.




A Recursive Factorial Function.




A Shape Type Class. Each Type provides its own Area implementation. Sub-Types provide relations on the properties of their parent Types.

# Summary

- Start with Functional programming (Haskell).
- Add a “memory” function; a non-blocking register.
- Instantiation followed by cyclical execution determined by the sampling rate.
- A type system whose instantiated objects have “state”.
- Simplified object and inheritance model.
- C like syntax. But not C or Java compatible.
- Execute on simple stack machine(s) or translate into hardware.