occam on the Arduino

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also featuring photos by:
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Finding a platform

• We merged the Transterpreter into the KRoC tree a while ago, but we've only worked on one port recently – the Surveyor robot

• The Surveyor costs $400, and is cute but not terribly robust

• Other ports we've done in the past (the Pioneer, the Lego Mindstorms, and various one-off robots) have been similarly expensive
The Arduino

- Family of AVR-based development boards
- Costs $25
  - Cheaper in bulk
- Open-source hardware and software
  - Anyone can build their own Arduino variants – and lots of people have done
  - Simple bootloader
  - Simple IDE
- Huge community – http://www.arduino.cc/
The plan

• Port the Transterpreter to the Arduino
  – ... which is really “port it to the AVR processor”

• Provide a toolkit of processes for people to build interesting things with
  – The Arduino's C++ library is called Wiring...
  – ... so our occam library is called Plumbing

• Write a book that introduces students to embedded programming with Plumbing
  – Primarily aimed at non-techies – lots of artists and musicians use Arduinos
Squeezing occam into not much space

- The ATmega328P on the Arduino is a reasonably typical low-cost microcontroller
  - 32KiB flash, 2KiB RAM
  - 16MHz, 16-bit (effectively) CPU
  - Lots of IO facilities: ports, timers, interrupts, UARTs, ADCs...
  - Just the chip costs $4

- We use the normal occam-on-a-small-machine tricks: use 16-bit mode, disable most -pi features
Nonetheless, we have the will!

- The AVR is a Harvard-architecture design
  - Separate address spaces for instructions and data
- By default, the AVR C compiler *copies* data from flash into RAM on startup
- We implemented a virtual memory backend for the Transterpreter so we can keep TVM bytecode in flash
  - ... and a trimmed-down bytecode loader to support it
  - Room for ~14KiB of bytecode at the moment
The Arduino comes with a bootloader that lets you upload chunks of data into flash over the USB port – that's what makes it an Arduino!

The USB interface is quite slow, so it's a pain having to upload the Transterpreter every time you change your program...

... so we've fixed it so you don't have to

We use the existing bootloader; the Arduino is still an Arduino
And just about that time she calls me up

• Handling interrupts in occam is an interesting problem – but we have to do it!

• Carl and Jon had come up with a scheme to map interrupts to channels on the Surveyor that worked, but was too memory-hungry for our purposes
  – The AVR has lots of interrupts and very little RAM

• Came up with an approach that only needs two words per interrupt – works nicely
  – ... after some subtle debugging
Success!

- The traditional Arduino demo is to blink the built-in LED on and off
  - Easy to do in occam, of course...
- Of course, since this is occam, we can blink all the IO lines on and off in parallel, at different rates
  - This is extremely hard to do in C++!
- We’ve also done: buttons, serial communications, ADC, pin change interrupts...
64 LEDs (well, 128, actually...)
A real application

- 8x8 LED matrix
  - 8 rows and 8 columns, with an LED at each vertex
  - The AVR isn't really designed to drive that many LEDs directly off its IO pins, but it does work...

- Need to scan reasonably fast to draw graphics
- Need to buffer data as it's passed along the display
How does that work?
How does that work?
How does that work?
Distributed embedded system

source → buffer → buffer → buffer → ... → buffer → black. hole

column → column → column → ... → column
First node

source ➔ buffer ➔ buffer ➔ buffer ➔ ... ➔ buffer ➔ serial.tx

column ➔ column ➔ column ➔ ... ➔ column
Other nodes

serial.rx → buffer → buffer → buffer → ... → buffer → serial.tx

column → column → column → ... → column
The RepRap

- Homebrew 3D printer
  - Builds up 3D models layer by layer in ABS plastic
- Controlled by an Arduino board
- The existing firmware is complete rubbish
- Matt plans to get a student to reimplement it in occam using the Transterpreter...
Any questions?