Test-Driving the Internet of Things

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Agile Cambridge 2015

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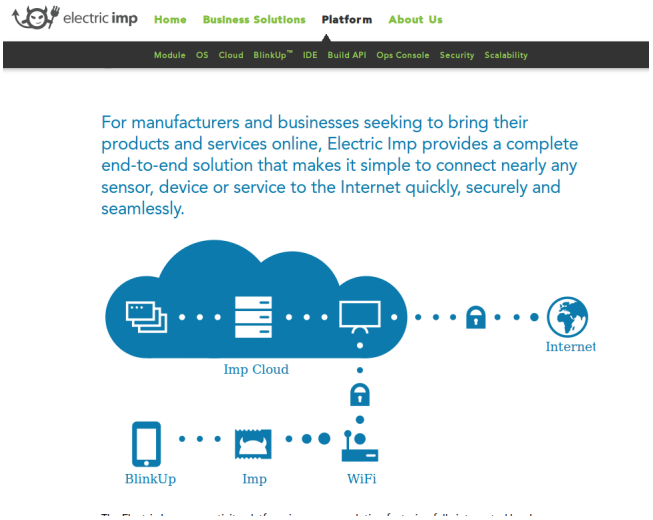
Contents

electric imp

The Electric Imp Connectivity Platform

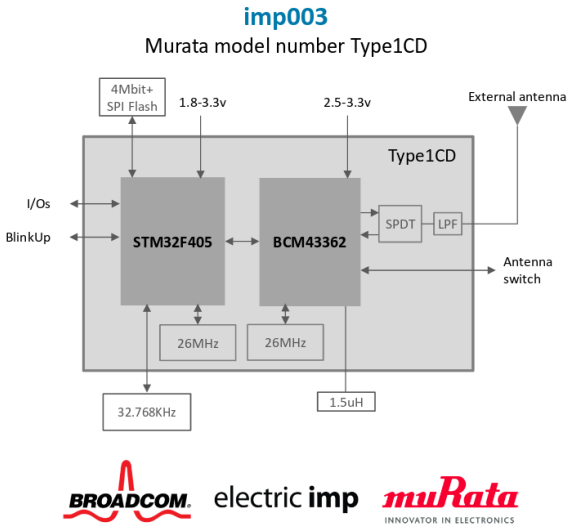


Electric Imp is a connectivity platform

The aim is to let manufacturers do what they're good at - product design and delivery

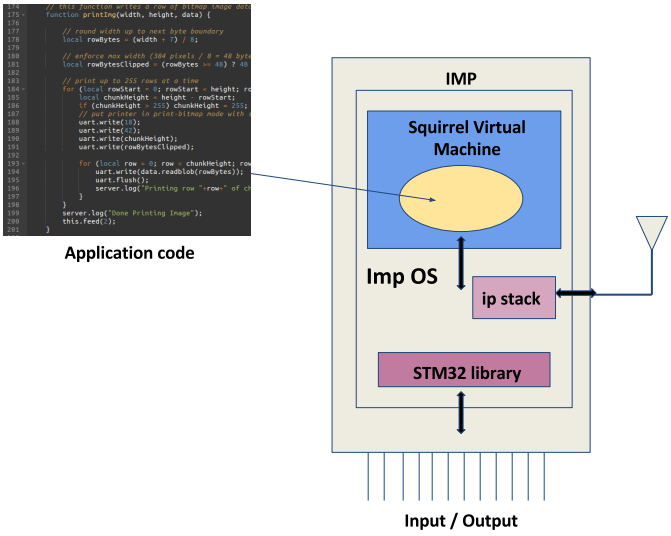
We take care of connecting devices, in-field updates, security and all that.

Components: the imp module



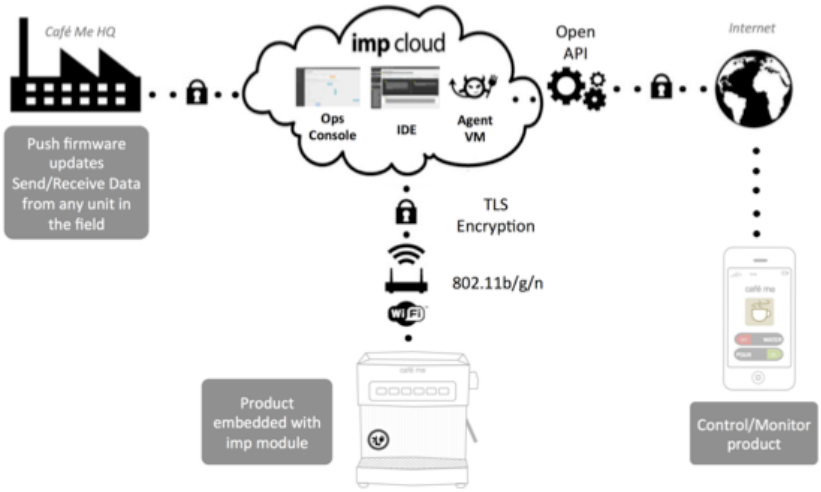
- Example imp 003.
- STM 32-bit flash microcontroller based on ARM Cortex M processor.
- IOs: GPIOs, UART, SPI, I2C, sampler, fixed frequency DAC etc etc.
- BCM 43362: broadcom wifi chip designed for low power, mobile use. 2.4 GHz WLAN.
- External flash
- Phototransistor for blinkUp
-

Components: imp operating system



- On the imp, we run an operating system (the imp OS).
- It has an IP stack and wifi drivers for communicating over wifi
- STM32 library to drive the peripherals.
- Runs the Squirrel Virtual Machine for application specific code.

Components: imp cloud



- Each physical imp is paired with another squirrel VM in the cloud.
- AGENT.
- The imp talks to the agent, which then connects to the wider web.
- Agent can provide RESTful endpoints and can talk HTTPS/JSON and so on to other sites.

Components: imp open API

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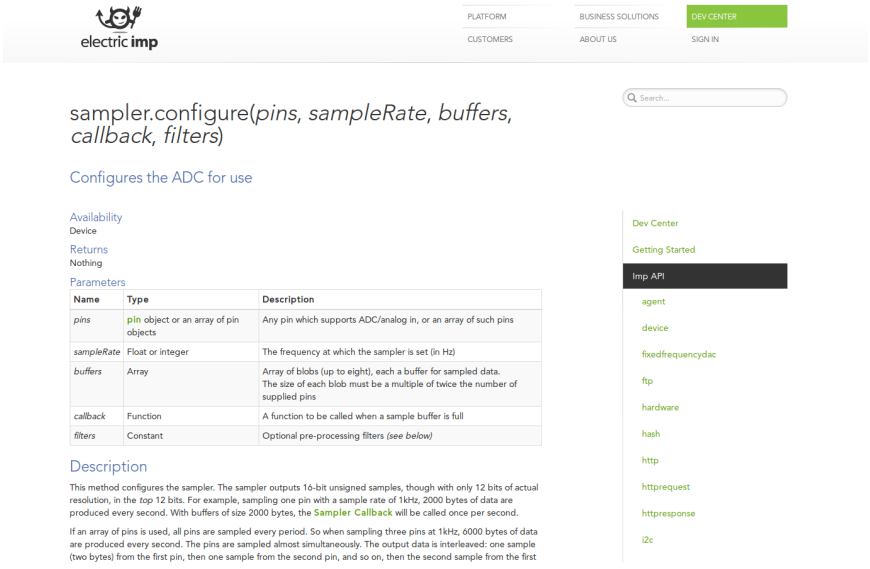
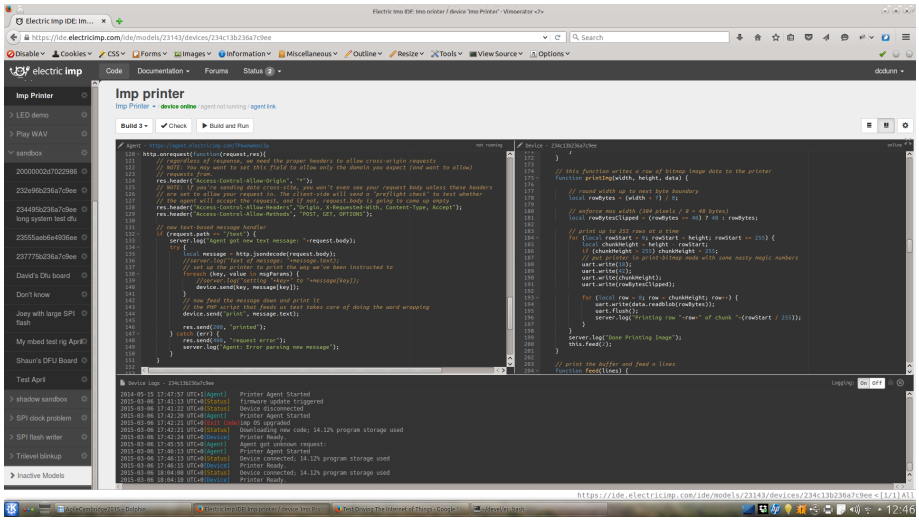


Curated IO.

- using BlinkUp we can teach the imp the credential of a local wifi access point.

Components: imp IDE



- the application code (imp and agent) is developed in a web browser, compiled and sent over the air to the device.
- a more sophisticated version exists for manufacturers
- e.g. can push code updates to all imps embedded in a given product.

Imp-enabled products

- Hiku: shopping
- Rachio: automated sprinkler. Takes weather forecasts from the web.
- Cybex: smart gym equipment
- Lockitron: smartphone operated door lock.
- EnOcean - monitoring and control systems for automated buildings

Unit-testing

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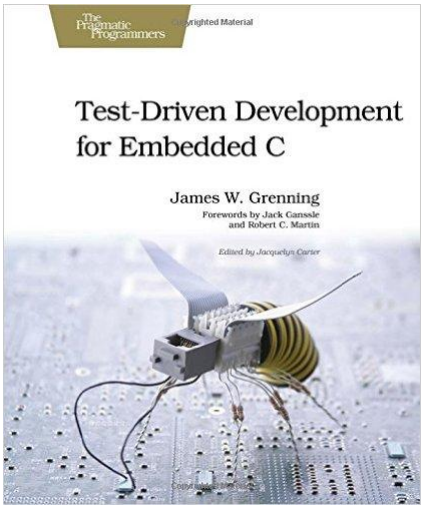
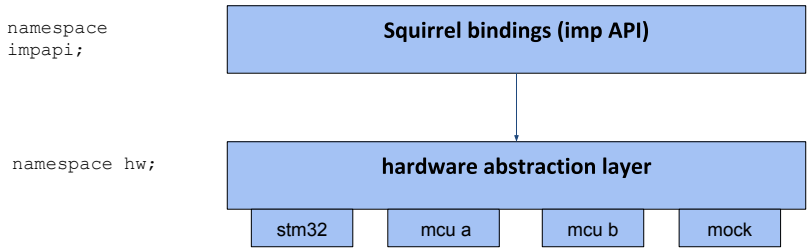


- **Compile your code to run on a PC as well as the target platform.**
- **We use C++**
- **googlemock**
- **“TDD one instruction away from the hardware”**

- We take Grenning’s book as the starting point.
- but use C++, which enables some of the techniques to be achieved more easily using the natural polymorphism of the language.
- googlemock: C++ framework inspired by jMock and hamcrest.

Unit testing: the imp api architecture



- Squirrel layer does parameter checking and passes control to the hw layer
- hw layer interacts with the hardware via third-party libraries.
- Squirrel layer also hands off waitables that can wake up squirrel on a hardware interrupt for example.

Unit-testing squirrel bindings

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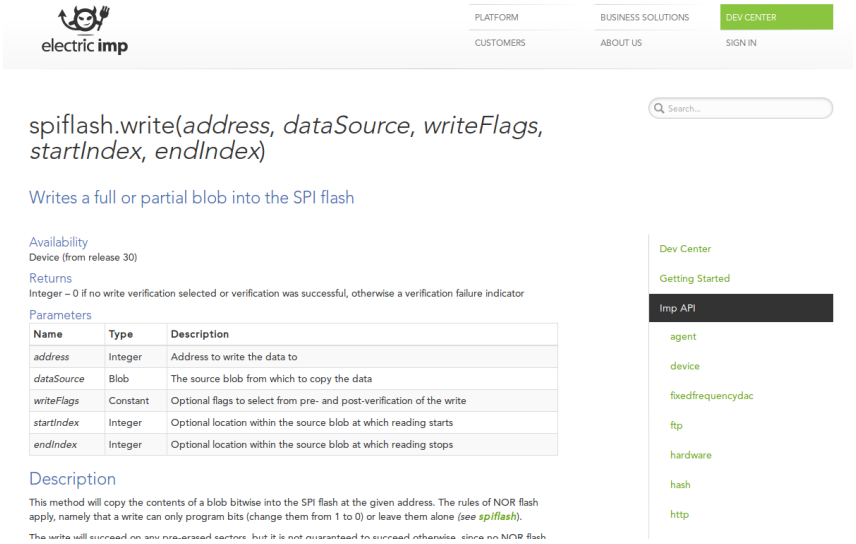

- Here is an API for using the external flash that comes with the imp003.

Unit testing squirrel bindings

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- The squirrel method `spiflash.write()` is bound to a method on a C++ class

```
SQInteger impapi::SpiFlash::write(HSQUIRRELVM vm);
```

- Objects such as these a) do parameter checking and b) forward to a hardware interface.
- Every bound function has the same signature, and takes a reference to the VM. We have developed a test fixture to simplify getting the VM into the right state for running a unit test.

- to run a unit test requires getting the VM into a particular state, which is not trivial.

Unit-testing squirrel bindings

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```
SQInteger SPIFlash::write(HSQUIRRELVM vm)
{
    const int nargs = sq_gettop(vm);
    Variable<int> address(vm, 2);

    if (nargs > 6 || !address.ok || !IsStringOrBlob(vm, 3)) {
        return ThrowBadParameters(vm, "spiflash", "write");
    }

    //... parameter crunching

    m_flashIo->write(address.value, data, bytes);

    return SQ_OK;
}
```

Unit-testing squirrel bindings

electric imp

```
void testCannotWriteToNegativeAddress()
{
    fixture.compile(
        "hardware.spiflash.enable();\n"
        "hardware.spiflash.write(-3, \"fred\");\n"
    );

    ASSERT_EQ(SQ_ERROR, fixture.run());

    ASSERT_THAT(fixture.messages(), ContainError("
        address out of range in spiflash.write()"));
}
```

- This shows unit tests for parameter checking: throw an error.

Unit-testing squirrel bindings

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```
void testWriteSendsCorrectDataWhenBlob()
{
    const uint32_t expectedAddress = 448*1024 + 1132;
    InSequence sequence;
    EXPECT_CALL(fixture.flash, select());
    EXPECT_CALL(fixture.flash, sendByte(hw::SPIFlash::WriteEnable));
    EXPECT_CALL(fixture.flash, sendByte(hw::SPIFlash::Write));
    EXPECT_CALL(fixture.flash, sendByte((expectedAddress & 0xff0000) >> 16));
    EXPECT_CALL(fixture.flash, sendByte((expectedAddress & 0xff00) >> 8));
    EXPECT_CALL(fixture.flash, sendByte(expectedAddress & 0xff));
    EXPECT_CALL(fixture.flash, write(NotNull(), 4)).With(Args<0,1>(ElementsAre('F', 'r',
'e', 'd')));
    EXPECT_CALL(fixture.flash, unselect());

    fixture.compile(
        "hardware.spiflash.enable();\n"
        "buffer <- blob();\n"
        "buffer.writestring(\"Fred\");\n"
        "hardware.spiflash.write(1132, buffer);\n"
     );
     ASSERT_EQ(SQ_OK, fixture.run());
}
```

- This shows (and documents) how the underlying flash interface must be invoked
- enable for writing
- write command
- 24-bit address in 3 bytes
- the data

Unit testing hw layer

electric imp

The stm32 implementation of the `hw::SPIFlash` class calls through to the hardware library, through functions such as `SPI_Init, SPI_Cmd` and so on.

These cannot be compiled and run on a PC.

Unit-testing hw layer - link-time seams

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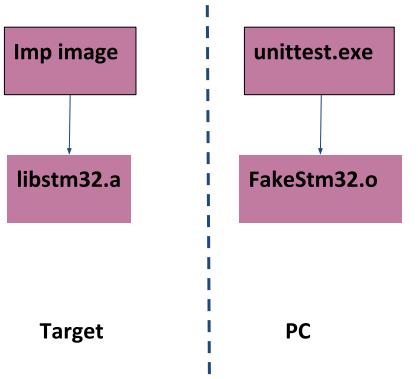
```
// stm32f2xx_spi.h
void SPI_Init(SPI_TypeDef*, SPI_InitTypeDef*);
void SPI_Cmd(SPI_TypeDef*, FunctionalState);
```




```
// FakeStm32.cpp

void SPI_Init(SPI_TypeDef* spi,
    SPI_InitTypeDef* initParams)
{
    mockSpi->init(spi, initParams);
}

void SPI_Cmd(SPI_TypeDef* spi,
    FunctionalState state)
{
    mockSpi->cmd(spi, state);
}
```

One instruction from the hardware

- #include the stm32 header on target and PC.
- Target imp image links the real stm32 library
- The unittest programme on the PC links a faked version of the library
- which uses mocks so we can use the gmock framework.

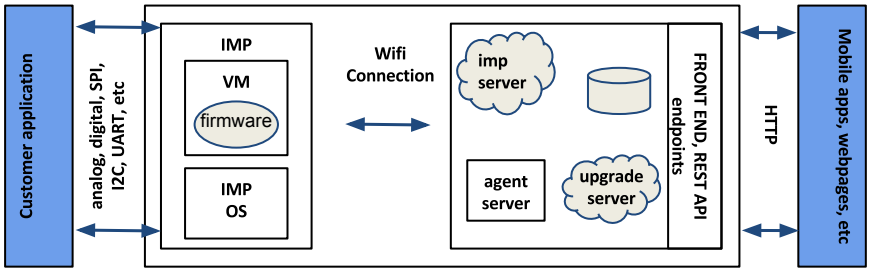
Unit-testing hw layer

electric imp

```
void testEnableInitialisesChipSelectPin()
{
    EXPECT_CALL(*fakeSTM32->gpio, init(GpioForLocation(0xAA),
        AllOf(
            GpioMode(GPIO_Mode_OUT),
            GpioOutput(GPIO_OType_PP),
            GpioPull(GPIO_PuPd_NOPULL),
            GpioPinMask(1u << PinForLocation(0xAA))
        )));

    spiFlash.enable();
}
```

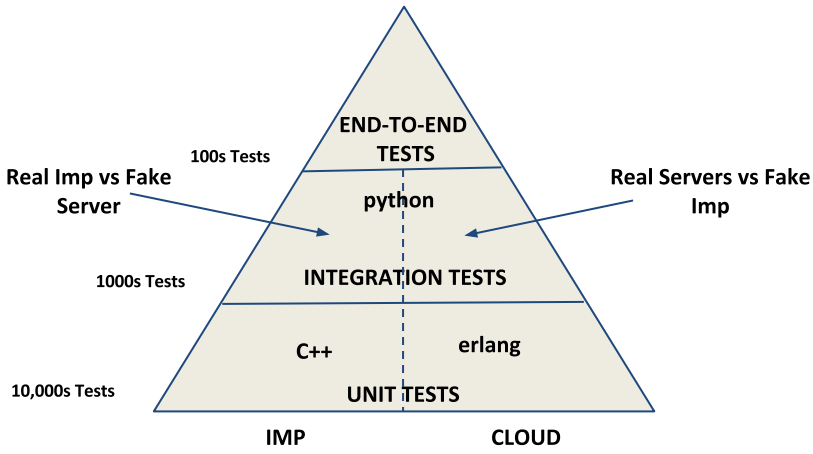
System testing: what is the 'system'?



- well and good to TDD against the documentation, but that says nothing about the real device
- in one hardware release the manufacturers inverted the sense of the power gates. All unit tests passed. Device dead.

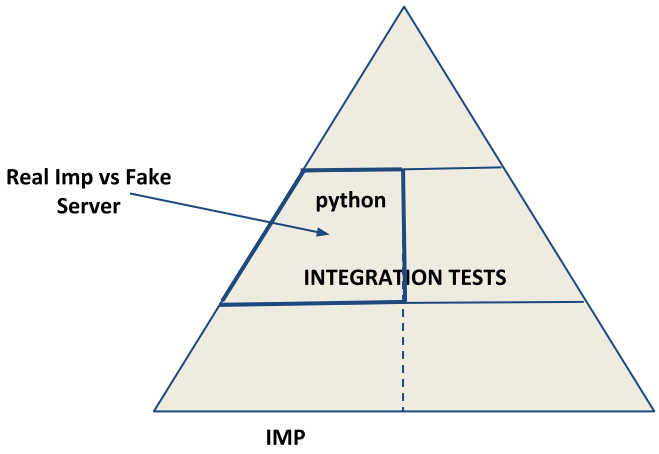
Testing hierarchy

electric imp

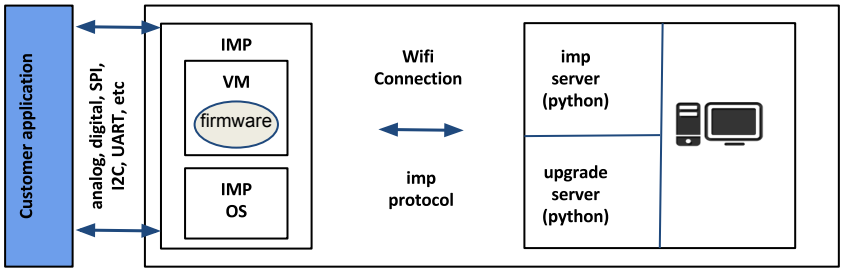


End-to-end hit REST API endpoints, test factory flow, production flow etc
The ends (crudely) are the imps I/O and the REST endpoints.

Testing hierarchy



Faking the cloud

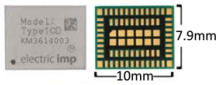


The imp only really sees the imp server and the peripherals, so all the complexity of server can be hidden behind an implementation of a server that speaks imp protocol.

We use iptables, dns forwarding and all that, so that the imp under test THINKS it is talking to the real electric imp cloud services.

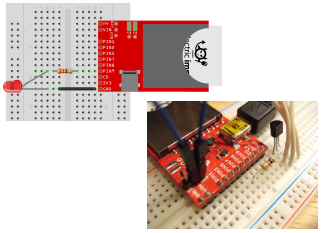
The test space

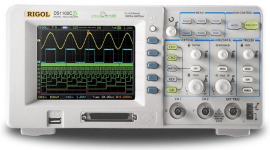
- Factory process
- BlinkUp and authentication
- LED patterns
- Joining Wifi (WEP, WPA, WPS etc)
- Communication with imp_server (get squirrel, agent <-> imp comms etc)
- imp OS upgrades
- Squirrel bindings for peripherals
- Non-functional requirements (image size, power consumption, time to boot etc)



Early efforts: ad hoc application specific testing

electric imp

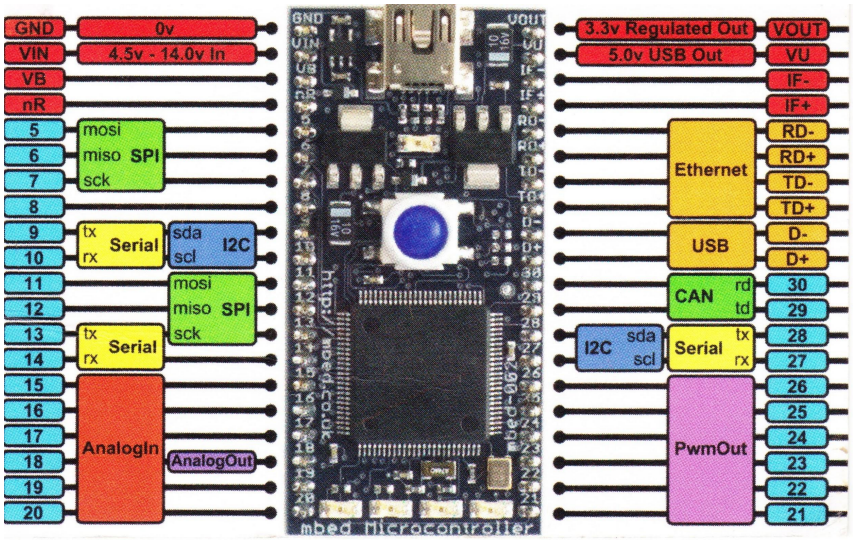




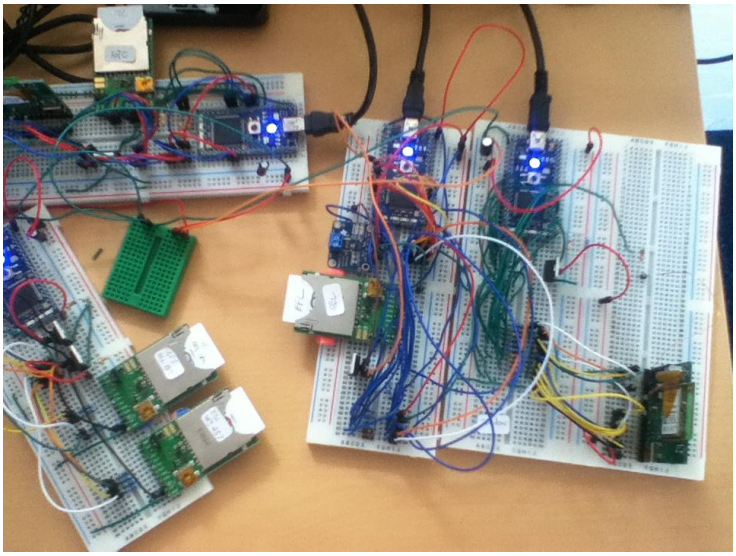
Knocking up little applications for targetted testing.
Manually blinking up to lots of acess points.
Whatever.

System testing - the mbed

electric imp

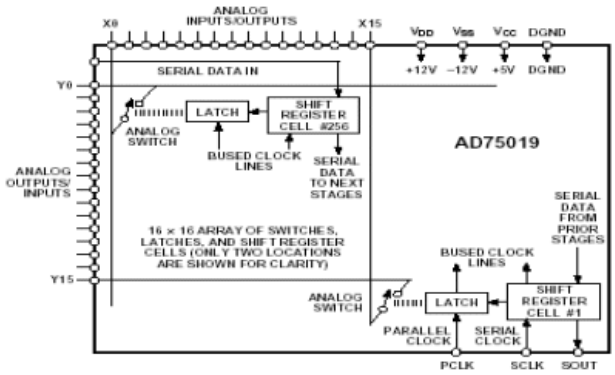


Hugo Vincent
mbed is development platform for Arm Cortex microprocessor
lots of GPIOs and peripherals
easy to program - connect to PC via USB
python RPC interface to mbed peripherals.
easy to run code on it - when plug in to pc (USB) get a file system and can copy your binary into it.
has python bindings for its RPC interface

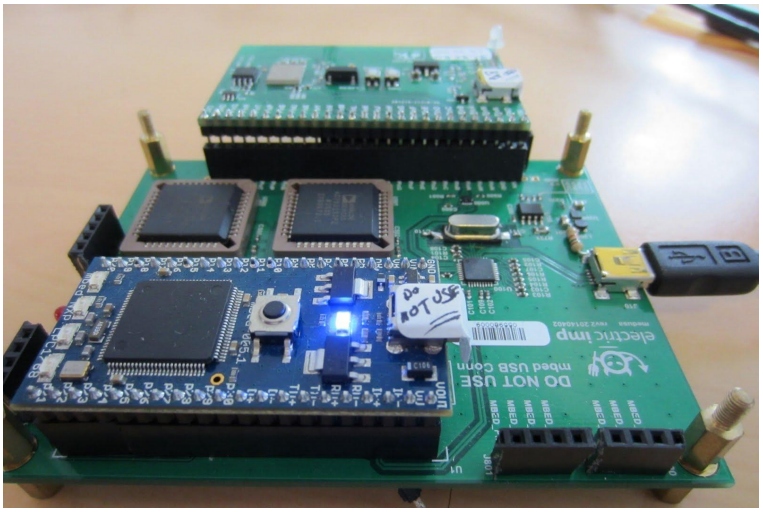


Breadboards targetting different peripherals.
e.g. GPIOs
SPI
I2C
BlinkUp
etc

System testing - switching

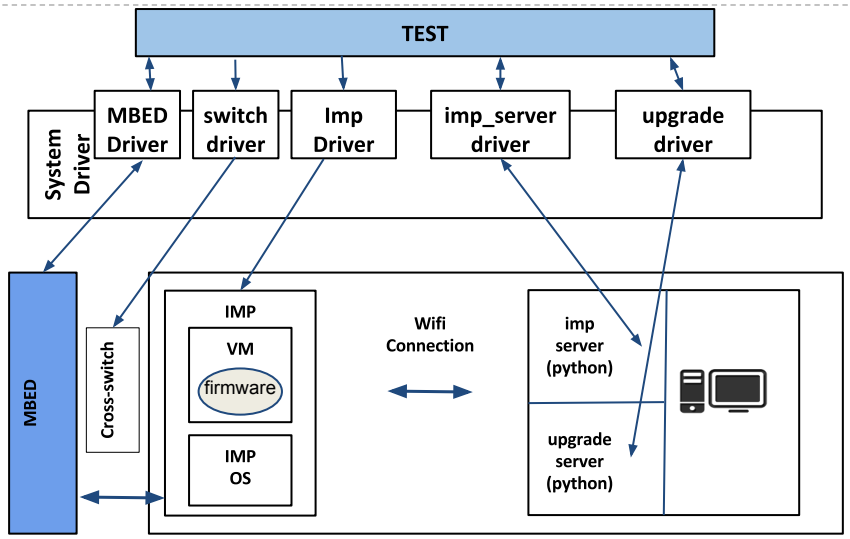


16x16 crosspoint switch
SPI interface to open or close connection between any pair of input/output



Need two switches to make all imp/mbed connections possible
Two headers so can plug in eel, shadow or joey.

A test harness



Credit where it's due

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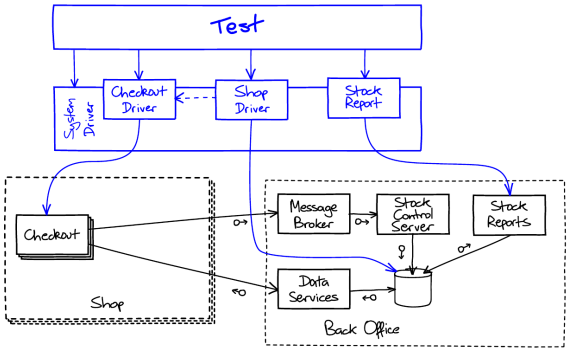

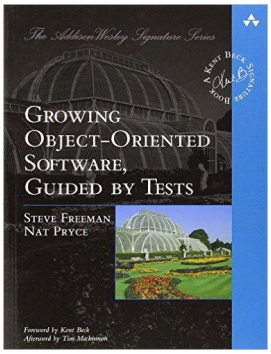

From "TDD at the System Scale", Agile Cambridge 2010, © Nat Pryce.

python and hamcrest

electric imp

- **python**
  - **out-of-the box assert framework, runner, reporter (unittest/nose)**
  - **lots of stable libraries for talking to hardware and the OS**
  - **good thread support for running fake servers etc.**
  - **can run tests at desk on command line**
- **has an implementation of Hamcrest:**
  - **a matcher library for writing easy to read tests**

System testing - a real test

electric imp

```
class TestExitCodes(ElectricImpTestCase):
 def setUp(self):
     self.imp.power_on()
     self.imp_server.received(handshake())

  def test_exit_code_for_firmware_upgrade(self):
     self.blinkup_imp().at_frequency(60).
         for_firmware_upgrade()
     self.imp_server.received(handshake(),
         last_exit_reason(firmware_upgrade())
```

This is hiding a lot of stuff - the python imp server, the mbed driver, the switching driver etc are all in the base class.

System testing - another real test

electric imp

```
class TestDigitalOut(ElectricImpTestCase):
  def setUp(self):
      self.mbedPin = mbed.DigitalIn("p10")
      self.connectImpToMbed("pin5", mbedPin)

  def test_digital_out_can_write_high(self):
      self.loadAndRunSquirrelCode("""
         hardware.pin5.configure(DIGITAL_OUT);
         hardware.pin5.write(1);
      """

      assert_that(mbedPin, is_high())
```

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System testing - another real test

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      assert_that(mbedPin, is_high())
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System testing - another real test

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      self.connectImpToMbed("pin5", mbedPin)

  def test_digital_out_can_write_high(self):
      self.loadAndRunSquirrelCode("""
         hardware.pin5.configure(DIGITAL_OUT);
         hardware.pin5.write(1);
      """
      sleep(2)
      assert_that(mbedPin, is_high())
```

All you've done is ensure the test takes two seconds longer to run.

- **Shared, thread-safe: updated by the system, examined by the test.**
- **Snapshot of this state captured atomically by the test and will not change while test is examining it.**
- **Look for success, not failure. Wait for system to enter expected state.**
- **Succeed fast. Snapshots can come from polling the system, or can be notified by the system.**
  - **Pollers**
  - **Notification traces**
- **We need all of this for our testing.**

System testing - another real test

electric imp

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  def setUp(self):
      self.mbedPin = mbed.DigitalIn("p10")
      self.connectImpToMbed("pin5", mbedPin)

  def test_digital_out_can_write_high(self):
      self.loadAndRunSquirrelCode("""
         hardware.pin5.configure(DIGITAL_OUT);
         hardware.pin5.write(1);
      """

      assert_eventually(mbedPin, is_high())
```
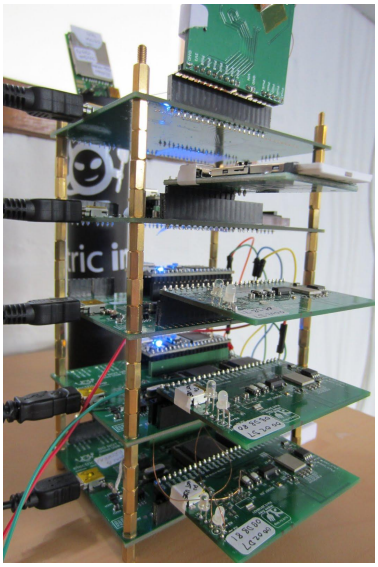

This is hiding a lot of stuff - the python imp server, the mbed driver, the switching driver etc are all in the base class.

The test harness



Workflow

electric imp