Pervasive Systems

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Lecture 21:
Wiselib: Algorithmic Library for WSN

A Library Of Algorithms

Typical Problems In WSN Programming

- Theoreticians are not interested in programming
  - Ideally they just have to write their algorithms
  - And do not need to care about boilerplate code
- Practioners are not interested in theory
  - Just need a good algorithm for their task
  - Without having to study the field for years

⇒ There is need for an algorithm library

- With lots of algorithms for all kinds of tasks
- That are easy to integrate into existing systems
- And are combinable
- And easily enhanceable

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Solution

The Wiselib

A library of about 50 algorithms, lots more to come! These are

- Extensible
- Combineable
- Exchangeable

Currently includes the following algorithm categories

- Clustering
- Graph Coloring
- Crypto
- Energy Preservation
- Localization
- Metrics
- Routing
- Synchronization
- Topology Control
- Tracking

The Wiselib is. . .

- A C++ project
- Free (as in freedom), licensed under LGPL
- **NOT** a middleware (we will see later why)

`github.com/ibr-alg/wiselib`

There you'll find:

- The Documentation Wiki
- The Wiselib Sourcecode
- The Bugtracker
- Instructions on how to download & install the Wiselib

Wiselib Distributions

Testing

- Under development
- Not necessarily tested on all platforms
- New things that may still change their interface
- "Release early, release often"

Stable

- Tested on all supported platforms
- Interfaces will not change anymore

Platform Independence

- When scientists all over the world work together, they likely use different experimentation environments
- The Wiselib aims to be **versatile**
  - So it can be used for **different tasks**
  - Which also require **different hardware**
- In lots of applications we need **heterogeneous nodes**
  - But do not want to write the same code again and again for each node type

→ We want the Wiselib to be platform independent!

Platform Independence

	iSense	**iMote2**	**ScatterWeb MSB**	**Tmote Sky**
				
Hardware	Jennic	Intel XScale	MSP430	MSP 430
Operating System	iSense	TinyOS	Scatterweb / Contiki	Contiki / TinyOS
ROM / RAM	128kB / 92kB	32MB / 32MB	48kB / 10kB	48kB / 10kB
Memory Management	Dynamic	Dynamic	Static	Dynamic
Programming Language	C++	nesC	C	C, nesC

Platform Independence

- Some platforms do not provide dynamic memory
- And/or have limited RAM
- Some do not provide a C++ environment
  - No libstdc++
  - So no exception handling, RTTI, virtual inheritance, etc...

The "extremely portable" subset of C++

- C (except `malloc` / `free`)
- Static memory management
- "Simple" (non-virtual) inheritance
- Templates
- Use C-Headers (`<math.h>` instead of `<cmath>`)

The Wiselib adheres to those conditions!

Memory Management

Platform independence demands:

- No `malloc/free` or `new/delete`

→ Data can be allocated in 3 ways:

- Global
- Static
- On the stack (function-local)

- Constructors of global/static variables will be called before `main()`
- . . . in undefined order!
- That can be very undesirable:

```
1 Radio radio;
2 SomeAlgorithm algo(radio); // Might receive uninitialized radio!
```

→ Provide `init()/destruct()` methods, call them manually

→ Hide initialization method of system objects ("Facets")

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Inheritance

Problem: Virtual inheritance is not portable.

What would we use virtual inheritance for?

→ **Code reuse**
Base class provides functionality which can be used by derived class
- Still possible with non-virtual inheritance

→ **Abstraction**
Define an *interface* which *classes* can use to interact with each other
- An algorithm only has to know the interface of the things its using, the concrete implementation is exchangeable

We want both!

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Abstraction With Templates

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Inheritance

Do it with templates!

- The "interface" is given by a piece of documentation, called **Concept**
- An algorithm expects a template parameter for the type of the concrete class, which is called **Model**

Template Based Design

```
1 class iSenseRadioModel {
2   int enable_radio() {}
3 }
```

```
1 class ShawnRadioModel {
2   int enable_radio() {}
3 }
```

```
1 template<typename Radio_P>
2 class Algorithm
3 {
4   typedef Radio_P Radio;
5
6   int init( Radio& radio ) {
7     radio_ = &radio;
8     radio_->enable_radio();
9   }
10
11  Radio::self_pointer_t radio_;
12 }
```

```
1 Algorithm<iSenseRadioModel> algrithm_isense;
2 Algorithm<ShawnRadioModel> algrithm_shawn;
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Abstraction

Concept

- Describes behaviour of components
- E.g. "A Radio has a void send(char*) method"
- Only documentation

Model

- Actual class
- Implements any number of concepts
- E.g. A routing protocol may implement the radio concept
- ...so it can be used like one

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How Usable Is The Template Approach?

- There are other ways to provide abstraction
  - In C, one would usually abstract with **function pointers**
  - In C++ one would use **virtual inheritance**

How do they compare to the template approach?

Abstracting with C function pointers

```
1 // C
2 typedef struct {
3   int (*value)(void);
4 } Concept;
5
6 int model_value() { return 5; }
7 Concept model = { .value = &model_value };
8
9 void algorithm(Concept *c) {
10   // pointer->pointer->function
11   int v = c->value();
12 }
13
14 int main(int argc, char** argv) {
15   algorithm(&model);
16 }
```

Abstracting with virtual inheritance

```
1 // C++
2 class Concept {
3   public:
4     virtual int value();
5 };
6
7 class Model : public Concept {
8   public:
9     int value() { return 5; }
10 };
11
12 class Algorithm {
13   public:
14     // reference->vtable->function
15     void init(Concept& c) { v = c.value(); }
16     int v;
17 };
18
19 int main(int argc, char** argv) {
20   Model m;
21   Algorithm a;
22   a.init(m);
23 }
```

Abstracting with templates

```
1 // C++
2
3 // concept "Concept" {
4 //   has an 'int value()' method
5 // }
6
7 class Model {
8   public:
9     int value() { return 5; }
10 };
11
12 template<typename Concept_P>
13 class Algorithm {
14   public:
15     // reference->function
16     void init(Concept_P& c) { v = c.value(); }
17     int v;
18 };
19
20 int main(int argc, char** argv) {
21   Model m;
22   Algorithm<Model> a;
23   a.init(m);
24 }
```

Comparing the results

After compiling (for jennic, using ba-elf-gcc/ba-elf-g++) with -Os:

```
1 text    data     bss     dec     hex filename
2   56       4       0      60      3c c.o
3   16       0       0      16      10 template.o
4  143       0       0     143      8f virtual.o
```

→ Template-based design is space efficient!
→ Template-based design produces fast code!
→ Template-based design is portable!

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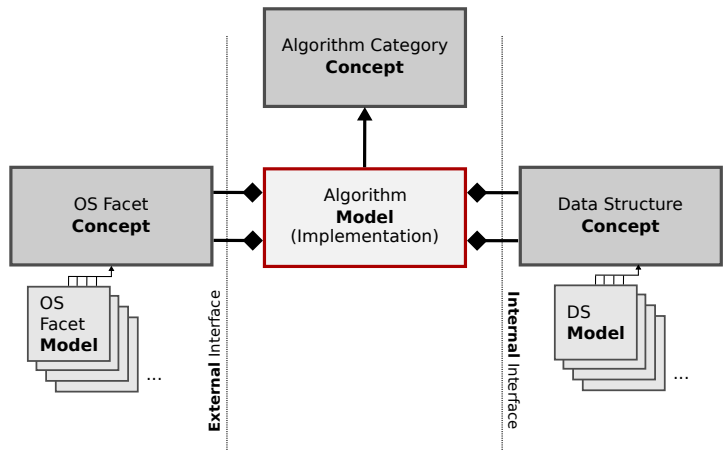

Types Of Concepts

Concept Organization

- Lots of models
- Lots of concepts
- Models that behave similar should share concepts
- E.g. A routing algorithm should be usable like a radio
  For the user, both are just things that
  - Can receive messages
  - Can send messages to nodes
  - Only the neighborhood is different!
- But a routing algorithm might have additional methods!

→ We want a (loose) hierarchy of concepts
→ We want to express concept inheritance
→ We want to have "base concepts" for general things

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Concept Architecture

The OsModel Facet

```
1  concept OsModel {
2    typedef ... size_t;
3    typedef ... block_data_t; // "byte"-like type for buffers
4    enum ReturnValues { SUCCESS = ..., ERR_UNSPEC = ..., ... };
5
6    typedef ... Radio; // Wireless communication facet
7    typedef ... Timer;
8    typedef ... Debug; // Send debug messages
9
10   static const Endianess endianess; // WISELIB_LITTLE_ENDIAN or
         WISELIB_BIG_ENDIAN
11 }
```

- Holds platform properties (like endianess, size type, etc...)
- Constants for return values
  - Include at least `SUCCESS` and `ERR_UNSPEC` (unspecified error)
  - May/will include more, similar to `errno`
- Holds types of other OS Facets

Concept Inheritance

```
1  concept RadioFacet {
2    typedef ... OsModel;
3    typedef ... node_id_t;
4    typedef ... block_data_t;
5    typedef ... size_t;
6
7    typedef ... message_id_t;
8
9    enum SpecialNodeIds {
10     BROADCAST_ADDRESS = ...,
11     NULL_NODE_ID      = ...
12   };
13   enum Restrictions {
14     MAX_MESSAGE_LENGTH = ...
15   };
16
17   int enable_radio();
18   int disable_radio();
19
20   int send(node_id_t receiver,
         size_t len, block_data_t *
         data );
21
22   node_id_t id();
23
24   // ....
25 };
```

← We "derive" another concept from this one:

```
1  concept VariablePowerRadioFacet
2    : public RadioFacet
3  {
4    // Everything in RadioFacet plus:
5
6    typedef ... TxPower;
7
8    int set_power(TxPower p);
9    TxPower power();
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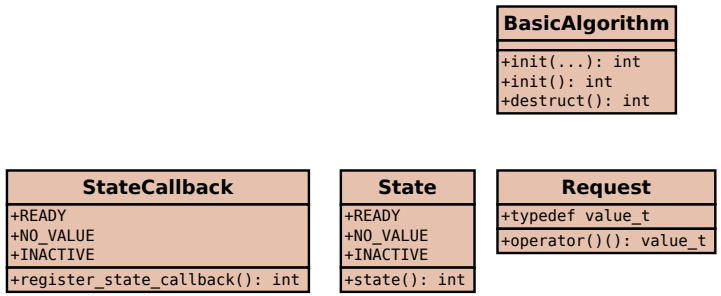

Basic Algorithm Manual initialization & destruction (so the order is defineable)

Request Produces values (can be polled with call-operator)

State Object is not guaranteed to be able to operate all the time

StateCallback Object can inform its user about state changes

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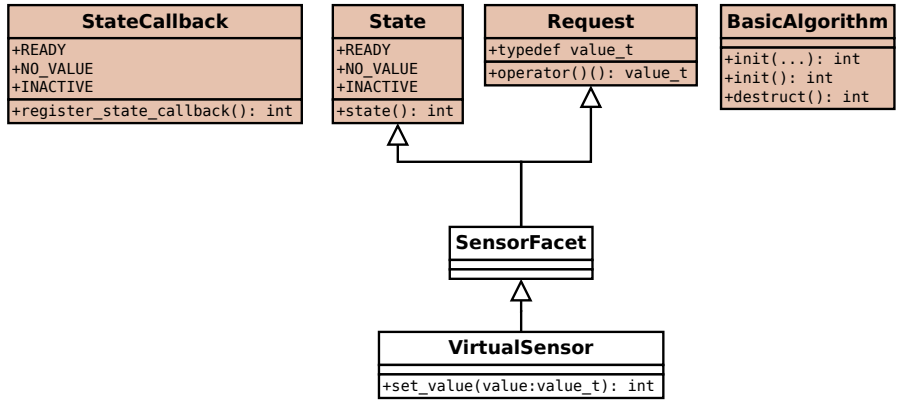

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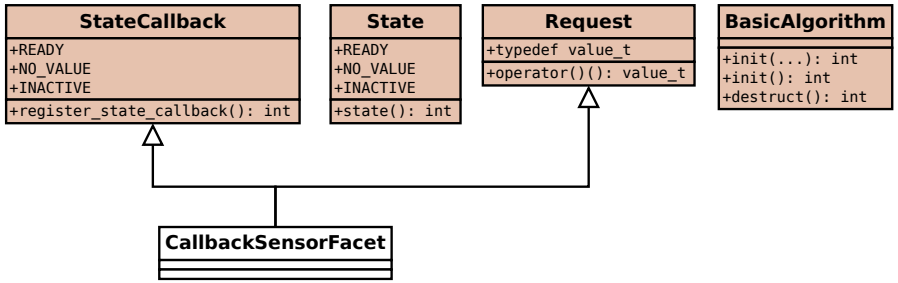

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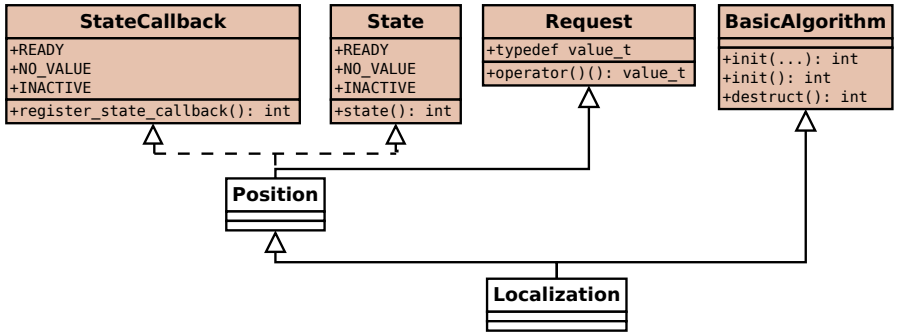

Stackability

Idea: Things with similar behaviour should share a concept!

Routing algorithms behave like radios
- They send and receive data to other nodes

→ Routing algorithms implement the *Radio Concept*

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Etc. . .

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Motivation | Design Of The Wiselib | Hardware Abstraction with OS Facets
Concept Architecture

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Stackability

- Create arbitrary complex applications
- Just by plugging together algorithms

Here:

1. "Physical" radio by iSense
2. AES-Encrypted node-to-node radio
3. Routing, all packets AES-encrypted node-to-node
4. All packets AES-encrypted node-to-node, payload ECC encrypted end-to-end

...can be used like a single simple radio!

Motivation | Design Of The Wiselib | Hardware Abstraction with OS Facets
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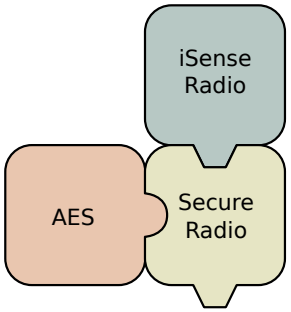

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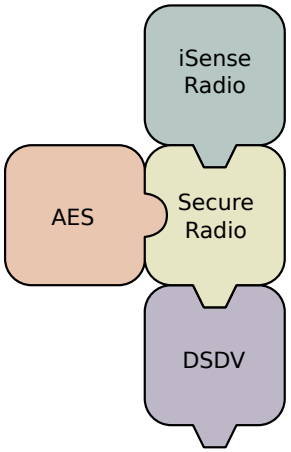

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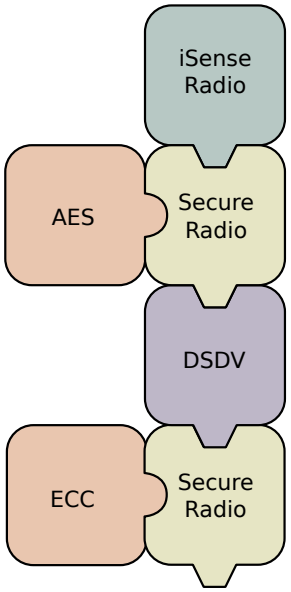

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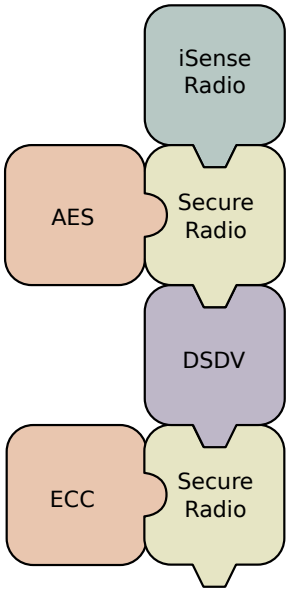

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Integration Demands

- Wiselib components should be easily integrable into existing code
- We want and/or need the full power of the platform. Examples:
  - Dynamically discover attached sensors
  - Fine-tuned device configuration

BUT

- Sometimes you want to run the same application on different platforms
- Advanced hardware settings are relatively unimportant

Two different integration mechanisms needed!

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Motivation Design Of The Wiselib Hardware Abstraction with OS Facets
Integrating The Wiselib

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Two different integration mechanisms needed!

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Integration Mechanisms

Direct Integration

→ Just use whatever parts of the Wiselib you like

⊕ Retain full power of your platform

⊕ Good if you have existing code

⊖ Not portable

Motivation Design Of The Wiselib Hardware Abstraction with OS Facets
Integrating The Wiselib

Integration Mechanisms

Generic Application

→ Write a Wiselib application class

⊕ Can be compiled for all Wiselib backends

⊖ You can only access the operating system through facets

⊖ But functionality will be limited to a common subset

E.g. you have to write "extremely portable" C++ (no `new`/`delete`, RTTI, exceptions, ...) in order to retain portability

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Direct Integration

```
// ...

void iSenseDemoApplication::boot(void) {
    os_.debug("WiselibExample::boot");
    routing_.enable();
    routing_.reg_recv_callback<
        iSenseDemoApplication,
        &iSenseDemoApplication::receive_routing_message>(this);

    os_.allow_sleep(false);
    os_.add_task_in(isense::Time(MILLISECONDS), this, 0);
}

// ...
```

- iSense specific code
- Wiselib specific code

Motivation | Design Of The Wiselib | Hardware Abstraction with OS Facets
Integrating The Wiselib
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iSense specific code
Wiselib specific code
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Generic Application

```
1 #include "external_interface/external_interface.h"
2 #include "external_interface/external_interface_testing.h"
3 // ...
4
5 typedef wiselib::PCOsModel Os;
6 class DemoApplication {
7   public:
8     void init(Os::AppMainParameter& amp) {
9       radio_ = &wiselib::FacetProvider<Os, Os::Radio>::get_facet(amp);
10      debug_ = &wiselib::FacetProvider<Os, Os::Debug>::get_facet(amp);
11
12      algorithm_.init();
13
14      radio_->enable_radio();
15      debug_->debug("Initialized.\n");
16    }
17
18  private:
19    Os::Debug::self_pointer_t debug_;
20    Os::Radio::self_pointer_t radio_;
21    SomeAlgorithm algorithm_;
22 };
23
24 wiselib::WiselibApplication<Os, DemoApplication> demo_app;
25 void application_main(Os::AppMainParameter& amp) {
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Platform selection

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Initialization: FacetProvider for OS facets / Manual for algorithms

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`application_main` getting called by Wiselib ↔ OS adaptor

What is a Facet?

- **Connection** between algorithms and OS
- **OS Facets** (Concepts)
  - OS Facet
  - Radio Facet
  - Timer Facet
  - ...
- For **each** supported OS at least **one model** per facet
  - iSenseOsModel
  - ContikiRadioModel
  - ShawnTimerModel
  - ...
- **Possible** to provide **muliple models** per facet
  - ContikiRimeRadioModel
  - Contiki6LowPanRadioModel
  - ...

Motivation | Design Of The Wiselib | Hardware Abstraction with OS Facets
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Motivation | Design Of The Wiselib | Hardware Abstraction with OS Facets
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Motivation | Design Of The Wiselib | Hardware Abstraction with OS Facets
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OS Facet Overview

	OS	Radio (TX Power Ext.) (RSSI/LQI Ext.)	Timer	Logging	Clock (Set Clock Ext.)	Serial Comm.	Position	
WP2 OSA	⊕	○	○	⊕				4/7
Contiki	⊕	○	⊕	⊕		○		5/7
TinyOS	⊕			⊕				2/7
iSense	⊕	⊕ ● ●	⊕	⊕	⊕ ●	⊕	○	7/7
ScatterWeb	⊕	○	⊕	⊕				4/7
Shawn	⊕	⊕ ● ●	⊕	⊕	⊕		⊕	6/7

(⊕ = fully supported, ○ = works / proof of concept, ● = with extension)

Exchangeability with Algorithms

- Basic design issue: **Flexibility**
- Pass an **algorithm** where a **facet** is expected
- Examples
  - Pass routing algorithm where radio is expected
    ⇒ Enable flexible multihop neighborhoods
  - Pass time-synchronization algorithm where clock is expected
    ⇒ Enable system-wide time basis
  - Pass localization algorithm where position is expected
    ⇒ Only some nodes in the network need to know their position
  - Pass routing-based debug model where debug facet is expected
    ⇒ Debug nodes that are not connected to a gateway position
- Advantage: Totally **transparent** for algorithm

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Motivation | Design Of The Wiselib | Hardware Abstraction with OS Facets
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The OS Facet

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```

- **Only** facet which does **not need** to be **instantiated**
- Provide **type definitions** and **constants**
- Platform properties (endianess, size type, ...)
- Constants for return values
  - Include at least SUCCESS and ERR_UNSPEC (unspecified error)
  - May/will include more, similar to errno
- Default types for basic OS Facets

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Radio Facet (1 of 4)

- Design issues
  - Abstraction to underlying hardware radio
  - Complex routing algorithms
  - *Virtual* radio providing *virtual* ids
- Send messages to other nodes
- Callback registration for received messsages
- Provide node id (and its **type**!)
  - Node id type is defined **per radio**
  - E.g., provide IP addresses, but run on 16-bit addresses
  - Only restriction: Be passed to `sizeof()`

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Radio Facet (2 of 4)

```
1  concept RadioFacet {
2    typedef ... node_id_t;
3    typedef ... block_data_t;
4    typedef ... size_t;
5    typedef ... message_id_t;
```

- Ability to provide **arbitrary** node ID types
- Message ID type to identify received messages

```
9    enum SpecialNodeIds { BROADCAST_ADDRESS = ..., NULL_NODE_ID = ... };
10   enum Restrictions { MAX_MESSAGE_LENGTH = ... };
```

- Basic constants for broadcasting and unknown nodes
- Maximal message length defined **per radio**

```
11   int enable_radio();
12   int disable_radio();
```

- Turn on/off radio
- Return `SUCCESS` or error code if failed

Motivation | Design Of The Wiselib | Hardware Abstraction with OS Facets
Important Facets
Radio Facet (2 of 4)
concept RadioFacet {
typedef ... node_id_t;
typedef ... block_data_t;
typedef ... size_t;
typedef ... message_id_t;
Ability to provide arbitrary node ID types
Message ID type to identify received messages
enum SpecialNodeIds { BROADCAST_ADDRESS = ..., NULL_NODE_ID = ... };
enum Restrictions { MAX_MESSAGE_LENGTH = ... };
Basic constants for broadcasting and unknown nodes
Maximal message length defined per radio
int enable_radio();
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Turn on/off radio
Return SUCCESS or error code if failed
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Radio Facet (3 of 4)

```
13      int send(node_id_t receiver, size_t len, block_data_t *data );
```

- Send message to `receiver` (either unicast or broadcast)
- Return `SUCCESS` or error code if failed

```
14      node_id_t id();
```

- Return node id: Can be of **arbitrary** type

```
15    template<class T, void (T::*TMethod)(node_id_t, size_t, block_data_t*)>
16    int reg_recv_callback(T *obj_pnt);
17
18    int unreg_recv_callback(int cid);
19  }
```

- Callback registration: Return *callback id* (or -1 if failed)
- Pass *callback id* to unregister callback

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Important Facets

Radio Facet (3 of 4)

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Radio Facet (4 of 4) - Derived Concepts

- VariablePowerRadio

```
1       typedef ... TxPower;
2
3       int set_power(TxPower p);
4       TxPower power();
```

  - Set transmission power
  - Read out TX power to work on value (increment, decrement, ...)

- ExtendedDataRadio

```
1       typedef ... ExtendedData;
2
3       template<class T, void (T::*TMethod)(node_id_t, size_t,
            block_data_t*,
4                                            ExtendedData&)>
5       int reg_recv_callback( T *obj_pnt );
```

  - Register **receive** method with additional parameter
  - Extended data can be LQI, RSSI, ...
    → Again a concept with different `ExtendedData`-models

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    → Again a concept with different `ExtendedData`-models

Timer Facet

- Event mechanism
- *Wait for given time, then call me back...*

```
1   concept TimerFacet {
2     typedef ... millis_t;
3
4     template<typename T, void (T::*TMethod)(void*)>
5     int set_timer(millis_t millis, T *obj_pnt, void *userdata);
6   }
```

  - Time given in milliseconds
  - Callback registration: Call passed method in given time
  - `userdata` is passed on callback

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Debug/Logging Facet

- Write out debug or logging data
- Equivalent to `printf()`

```
1   concept DebugFacet
2   {
3     void debug( const char *msg, ... );
4   }
```

  - Only one method: `debug(...)`
  - Usage as `printf()`
    ⇒ debug_->debug("print an int: %d", my_int);

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Clock Facet

- Access to system time
- Type defined by model (platform dependent)

```
concept ClockFacet {
  typedef ... time_t;

  enum ClockSpecificData { CLOCKS_PER_SEC = ..., };

  time_t time();
}
```

- Only one method: `time()`
- Number of clock tics per second (`CLOCKS_PER_SEC`):
  → Deal with platform independent time calculations

- Derived Concept: Settable Clock facet

```
int set_time( time_t time );
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  - Set time (e.g., for time-synchronization)
  - Currently only implemented for iSense

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Facet Structure

- **Construction** of facets **system dependent**
  - Shawn: A facet needs to know to which processor it belongs
  - iSense: Require access to `isense::Os`
  - Contiki: Only calls to C functions
- Each system with **own constructors**
- Generic Wiselib Application
  - **Construction** must be **hidden** for user
  - Solution: Template based **facet provider**
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  - Facets are **known** to user
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Generic Wiselib Application (1 of 2)

- Template `FacetProvider`
  → Internals in Session 4

```
1   template<typename OsModel_P,
2            typename Facet_P>
3   class FacetProvider {
4     static Facet& get_facet( AppMainParameter& os );
5   }
```

- Template **specialization** for different platforms
- Method `get_facet()` returns **reference to facet**

```
1   void init( Os::AppMainParameter& value )
2   {
3      radio_ = &wiselib::FacetProvider<Os, Os::Radio>::get_facet(
           value );
4    }
5   ...
6   Os::Radio::self_pointer_t radio_;
```

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Facet Instantiation

Generic Wiselib Application (1 of 2)

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Generic Wiselib Application (2 of 2)

- Special Issue: The self_pointer_t

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        value );
 }
 ...
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```

- Each facet/algorithm provides self_pointer_t
- Access via radio_->enable_radio()
- Usually, this is just a pointer
  → typedef self_t* self_pointer_t
- For C systems, this can be used to **optimize** code space

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iSense Application

- iSense facets usually expect `isense::Os` in constructor

```
template<typename OsModel_P>
class iSenseRadioModel
  : public isense::Receiver
{
  iSenseRadioModel( isense::Os& os )
    : os_(os)
  {
    os_.dispatcher().add_receiver( this );
  }
  ...
}
```

- Directly used as members

```
#include "external_interface/isense/isense_radio.h"
typedef wiselib::iSenseOsModel Os;

class iSenseDemoApplication {

  iSenseDemoApplication( isense::Os& os )
    : isense::Application(os),
      radio_( os )
  {}

  Os::Radio radio_;
}
```

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typedef wiselib::iSenseOsModel Os;

class iSenseDemoApplication {

  iSenseDemoApplication( isense::Os& os )
    : isense::Application(os),
      radio_( os )
  {}

  Os::Radio radio_;
}
```

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Shawn Application

- Shawn facets usually expect `ShawnOs` in constructor
  → Defined in `external_interface/shawn/shawn_types.h`

```
template<typename OsModel_P>
class ShawnRadioModel {
  ShawnRadioModel( ShawnOs& os )
    : os_(os)
  {}
  ...
  ShawnOs& os_;
```

- Directly used as members

```
#include "external_interface/shawn/shawn_radio.h"
typedef wiselib::ShawnOsModel Os;

class WiselibExampleProcessor
  : public virtual ExtIfaceProcessor {

  WiselibExampleProcessor()
    : wiselib_radio_ ( os_ )
  {}

  void boot() { os_.proc = this; }

  ShawnOs os_;
  Os::Radio wiselib_radio_;
```

Motivation | Design Of The Wiselib | Hardware Abstraction with OS Facets
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