Konfigurierbare Systemsoftware (KSS)

VL 2 – Software Product Lines

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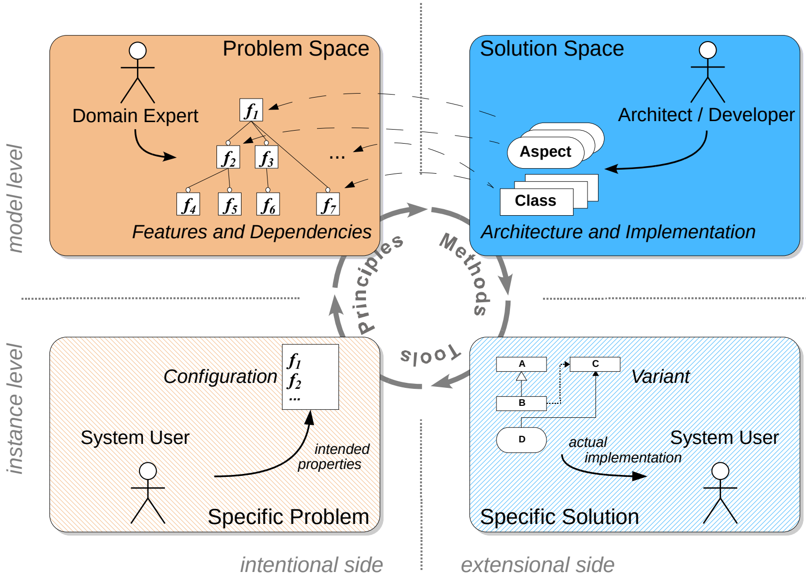
SS 16 – 2016-04-18

http://www4.informatik.uni-erlangen.de/Lehre/SS16/V_KSS

About this Lecture



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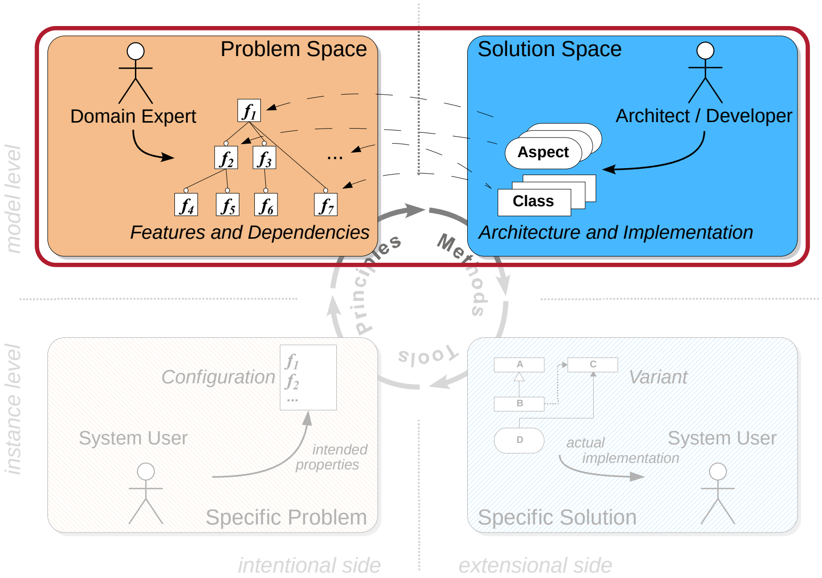


Agenda

Agenda

Model Car Industry: Variety of an BMW X3

- Roof interior: **90000** variants available
- Car door: **3000** variants available
- Rear axle: **324** variants available

> *“Varianten sind ein wesentlicher Hebel für das Unternehmensergebnis”*
>
> Franz Decker (BMW Group)

Model Car Industry: Variety Increase

- **In the 1980s: little variety**
  - Option to choose series and maybe a few extras (tape deck, roof rack)
  - A **single variant** (Audi 80, 1.3l, 55 PS) accounted for **40 percent** of Audi's total revenue
- **Twenty years later: built-to-order**
  - Audi: $\mathbf{10^{20}}$ possible variants
  - BMW: $\mathbf{10^{32}}$ possible variants
  - At average there are 1.1 equal instances of an Audi A8 on the street

↪ **Product lines** with fully automated assembly

33 optional, independent features

one individual variant for each human being

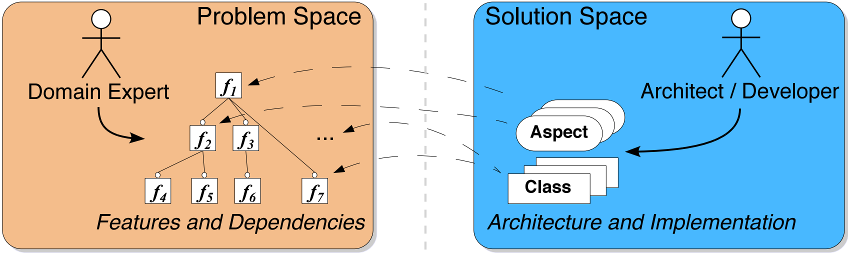

320
optional, independent
features
more variants than
atoms in the universe!

Typical Configurable Operating Systems...

5000 features

14000 features

Challenges



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Definition: (Software) Product Line, Feature

Product Line (Withey) (Definition 1)

*“A **product line** is a group of products sharing a common, managed set of **features** that satisfy the specific needs of a selected **market**.”*

Withey 1996: *Investment Analysis of Software Assets for Product Lines* [12]

Software Product Line (SEI) (Definition 2)

*“A **software product line (SPL)** is a set of software-intensive systems that share a common, managed set of **features** satisfying the specific needs of a particular **market** segment or mission and that are developed from a common set of core assets in a prescribed way.”*

Northrop and Clements 2001: *Software Product Lines: Practices and Patterns* [8]

Remarkable:
SPLs are not motivated by **technical** similarity of the products, but by **feature** similarity wrt a certain **market**

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Feature (Czarnecki / Eisenecker) (Definition 3)

“ A distinguishable characteristic of a concept [...] that is relevant to some stakeholder of the concept. ”

Czarnecki and Eisenecker 2000: *Generative Programming. Methods, Tools and Applications* [3, p. 38]

The Emperors New Clothes?

Program Family (Definition 4)

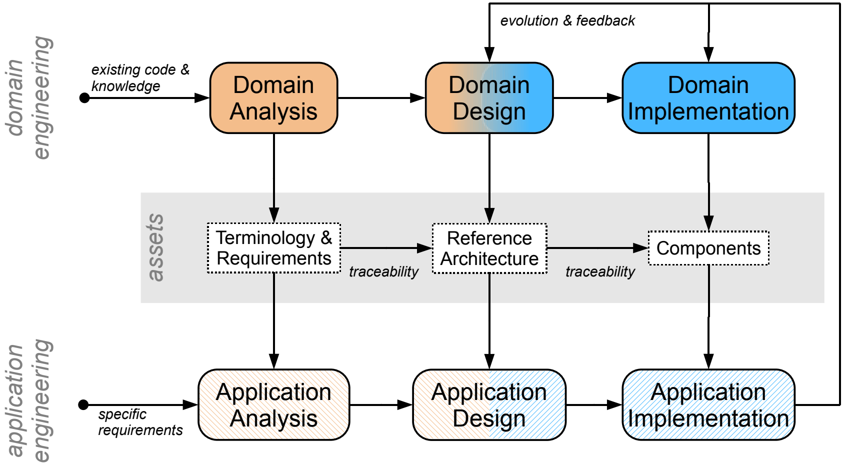
“Program families are defined [...] as sets of programs whose common properties are so extensive that it is advantageous to study the common properties of the programs before analyzing individual members.”

Parnas 1976: *“On the Design and Development of Program Families”* [10]

- Most research on operating-system *families* from the ’70s would today qualify as work on software product lines [2, 4, 5, 9–11]
  - Program Family $\rightleftharpoons$ Software Product Line
- However, according to the definitions, the viewpoint is different
  - Program family: defined by similarity between programs $\mapsto$ Solutions
  - SPL: defined by similarity between requirements $\mapsto$ Problems

  $\Rightarrow$ A program family implements a software product line
- In current literature, however, both terms are used synonymously
  - Program Family $\Longleftrightarrow$ Software Product Line

SPL Development Reference Process [1]



application engineering $\mapsto$ **tailoring**

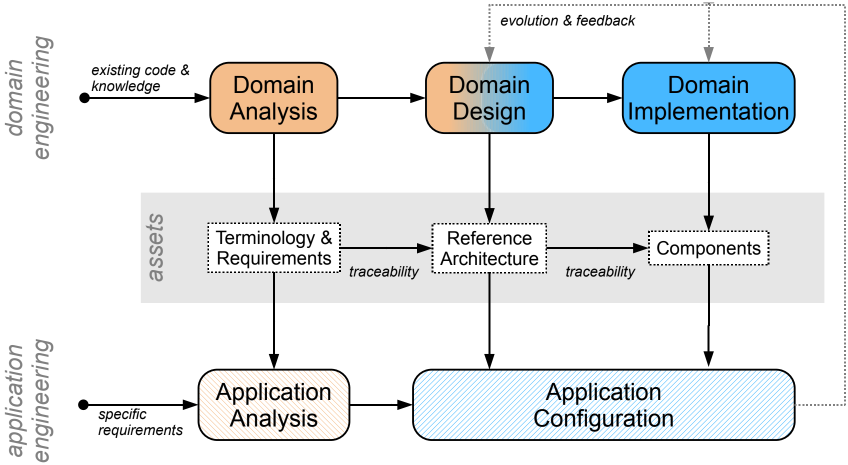
Our understanding: Configurable System Software

Configurability (Definition 5)

Configurability is the property that denotes the degree of pre-defined variability and granularity offered by a piece of system software via an explicit **configuration interface**.

- Common configuration interfaces
  - Text-based: `configure` script or `configure.h` file (GNU tools)
    - configuration by commenting/uncommenting of (preprocessor) flags
    - no validation, no explicit notion of feature dependencies
  - Tool-based: KConfig (Linux, busybox, CiAO, ...), ecosConfig (eCos)
    - configuration by an interactive configuration editor
    - formal model of configuration space, hierarchical features
    - implicit/explicit validation of constraints

Configurable SPL Reference Process

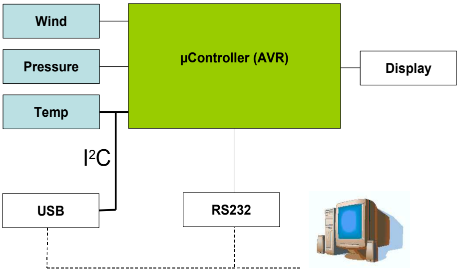


application engineering $\mapsto$ **configuring**

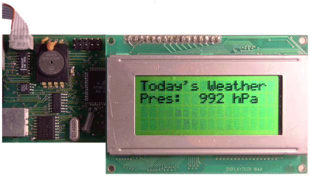
Agenda

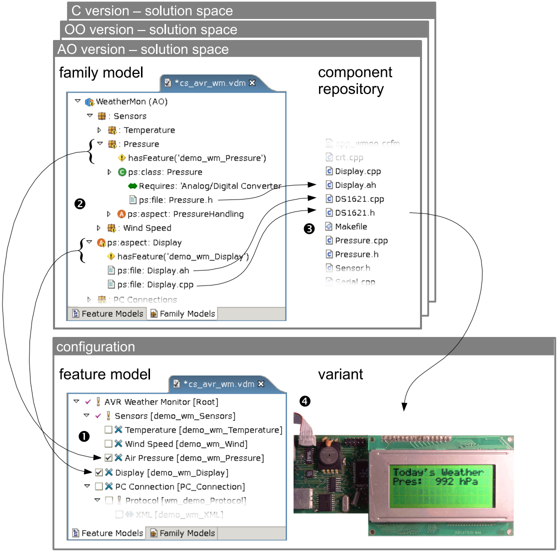
The i4WeatherMon Weather Station [7]

- A typical embedded system
  - Several, optional sensors
    - Wind
    - Air Pressure
    - Temperature
  - Several, optional actuators (here: output devices)
    - LCD
    - PC via RS232
    - PC via USB



- To be implemented as a product line
  - Barometer: Pressure + Display
  - Thermometer: Temperature + Display
  - Deluxe: Temperature + Pressure + Display + PC-Connection
  - Outdoor: <*as above*> + Wind
  - ...

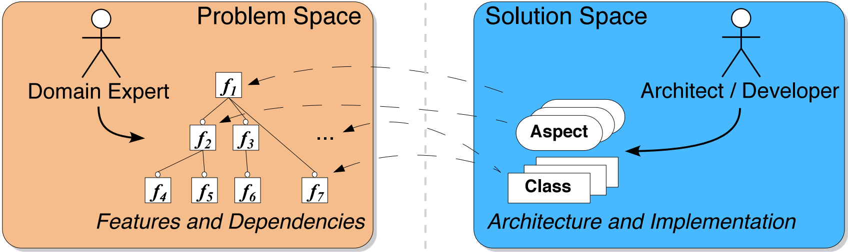




C version – solution space
OO version – solution space
AO version – solution space
family model
*cs_avr_wm.vdm
WeatherMon (AO)
: Sensors
: Temperature
: Pressure
hasFeature('demo_wm_Pressure')
ps:class: Pressure
Requires: 'Analog/Digital Converter'
ps:file: Pressure.h
ps:aspect: PressureHandling
: Wind Speed
ps:aspect: Display
hasFeature('demo_wm_Display')
ps:file: Display.ah
ps:file: Display.cpp
: PC Connections
Feature Models
Family Models
component repository
crt.cpp
Display.cpp
Display.ah
DS1621.cpp
DS1621.h
Makefile
Pressure.cpp
Pressure.h
Sensor.h
Serial.cpp
❶
❷
❸
❹
configuration
feature model
*cs_avr_wm.vdm
AVR Weather Monitor [Root]
Sensors [demo_wm_Sensors]
Temperature [demo_wm_Temperature]
Wind Speed [demo_wm_Wind]
Air Pressure [demo_wm_Pressure]
Display [demo_wm_Display]
PC Connection [PC_Connection]
Protocol [wm_demo_Protocol]
XML [demo_wm_XML]
Feature Models
Family Models
variant
Today's Weather
Pres: 992 hPa

Agenda

Challenges



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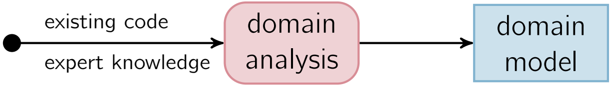
Domain Analysis



- **Domain Scoping**
  - Selection and processing of domain knowledge
  - Restriction of diversity and variety
- **Domain Modelling**
  - Systematic evaluation of the gained knowledge
  - Development of a taxonomy

⇝ Domain Model (Definition 6)

> “*A **domain model** is an explicit representation of the **common** and the **variable** properties of the system in a domain, the semantics of the properties and domain concepts, and the dependencies between the variable properties.*”
>
> Czarnecki and Eisenecker 2000: *Generative Programming. Methods, Tools and Applications* [3]

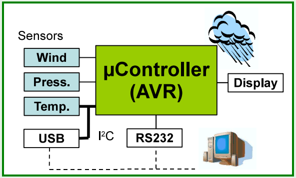
Elements of the Domain Model

- Domain definition specifies the scope of the domain
  - Examples and counter examples
  - Rules for inclusion/exclusion of systems or features
- Domain glossary defines the vocabulary of the domain
  - Naming of features and concepts
- Concept models describe relevant concepts of the domain
  - Formal description (e.g., by UML diagrams)
  - Textual description
  - Syntax and semantics
- Feature models describe the common and variable properties of domain members
  - Textual description
  - Feature diagrams

I4WeatherMon: Domain Model (simplified)

Domain Definition: i4WeatherMon

- The domain contains software for the depicted modular hardware platform. Future version should also support new sensor and actuator types (humidity, alarm, ...).
- The externally described application scenarios thermometer, PC, outdoor, ... shall be supported.



- The i4WeatherMon controller software is shipped in the flash memory of the μC and shall not be changed after delivery.
- The i4WeatherMon shall be usable with all versions of the PC Weather client software.
- ...

I4WeatherMon: Domain Model (simplified)

Domain Glossary: i4WeatherMon

- **PC Connection:** Optional communication channel to an external PC for the sake of continuous transmission of weather data. Internally also used for debug purposes.
- **Sensor:** Part (1 or more) of the i4WeatherMon hardware that measures a particular weather parameter (such as: temperature or air pressure).
- **Actuator:** Part (1 or more) of the i4WeaterMon hardware that processes weather data (such as: LCD).
- **XML Protocol:** XML-based data scheme for the transmission of arbitrary weather data over a PC Connection.
- **SNG Protocol:** Binary legacy data scheme for the transmission of wind, temperature and air pressure data only over a PC Connection. The data scheme is used by versions < 2.0 of PC Weather.
- ...

I4WeatherMon: Domain Model (simplified)

Concept Models: i4WeatherMon

- **XML Protocol:** The following DTD specifies the format used for data transmission over a PC Connection:

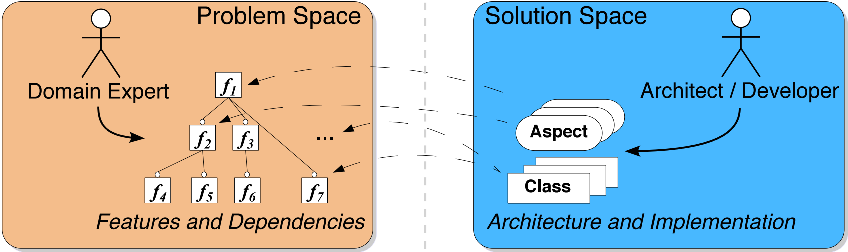
```
<!ELEMEMENT weather ...> ...
```

- **SNG Protocol:** Wind, temperature and air pressure data are encoded into 4 bytes, sequentially transmitted as a 3-byte datagram over a PC Connection as follows:

```
...
```

- **PC Connection** ...
- ...

Challenges



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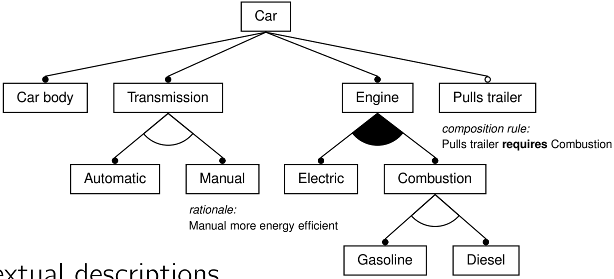
Feature Models

- Describe system variants by their commonalities and differences
  - Specify configurability in terms of optional and mandatory features
  - Intentional construct, independent from actual implementation

- Primary element is the **Feature Diagram**:
  - Concept (Root)
  - Features
  - Constraints



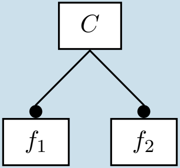
- Complemented by textual descriptions
  - Definition and rationale of each feature
  - Additional constraints, binding times, ...

Feature Diagrams – Language [3]

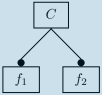
Syntactical Elements

The filled dot • indicates a mandatory feature:

$\mathcal{V} = \{(C, f_1, f_2)\}$



(a) Mandatory features f_1 and f_2 have to be included if their parent feature C is selected.



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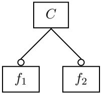

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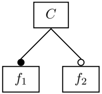

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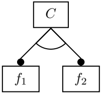

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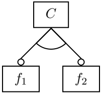

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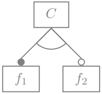

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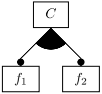

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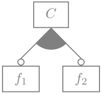

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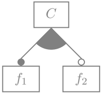

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Feature Diagrams – Language [3]

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A shallow dot $\circ$ indicates an optional feature:
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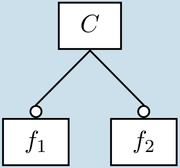

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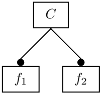

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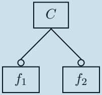

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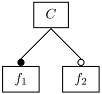

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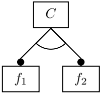

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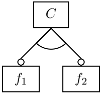

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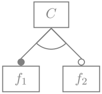

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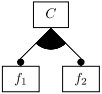

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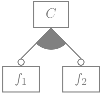

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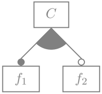

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Feature Diagrams – Language

Syntactical Elements

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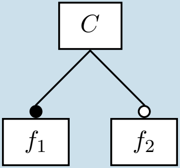

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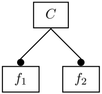

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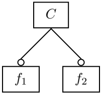

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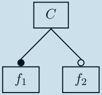

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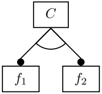

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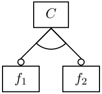

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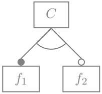

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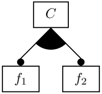

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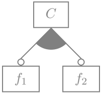
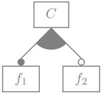


(h) *Not used. Eqivalent to* **(b)**.



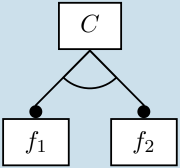
(i) *Not used. Equivalent to* **(b)**.

Feature Diagrams – Language [3]

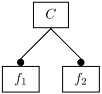
Syntactical Elements

The shallow arc ◠ depicts a group of alternative features:

$\mathcal{V} = \{(C, f_1), (C, f_2)\}$



(d) Exactly one **alternative feature** f_1 or f_2 has to be included if the group's parent feature C is selected.



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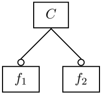
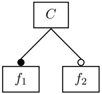
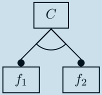


(b) Optional features f_1, f_2 can be included if their parent feature C is selected.



(c) Mandatory feature f_1 has to be included, **optional feature** f_2 can be included if their parent feature C is selected.



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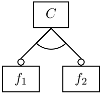

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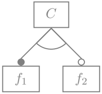
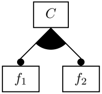


(f) *Not used. Equivalent to* **(e)**.



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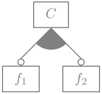

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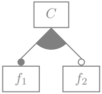

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Syntactical Elements

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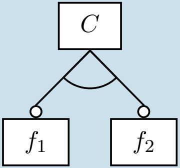

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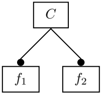

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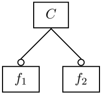

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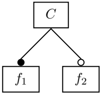

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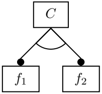

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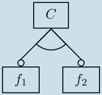

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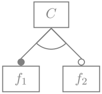

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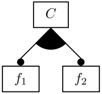

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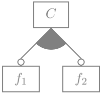

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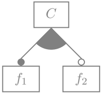

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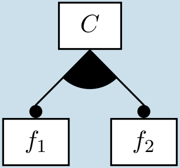

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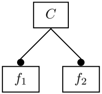

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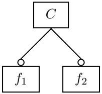

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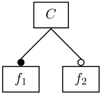

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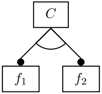

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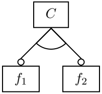

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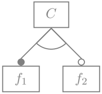

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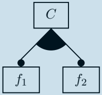

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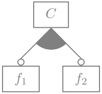

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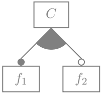
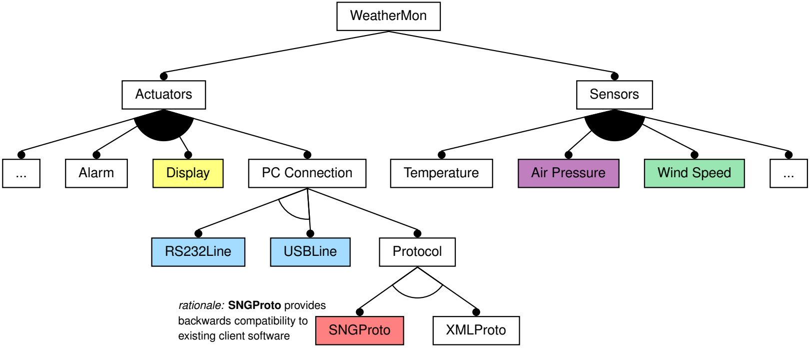


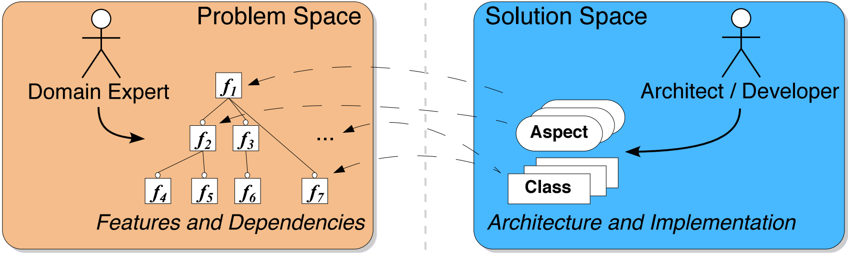
(i) *Not used. Equivalent to* **(b)**.

I4WeatherMon: Feature Model



rationale: **SNGProto** provides backwards compatibility to existing client software

Challenges



❶ How to **identify** the actually desired variability?

❷ How to **express** the intended variability?

❸ How to **implement** this variability in the code?

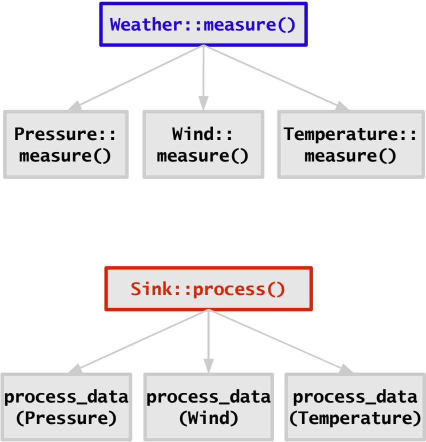
❹ How to **map** variability options to the code?

Agenda

I4WeatherMon: Reference Architecture

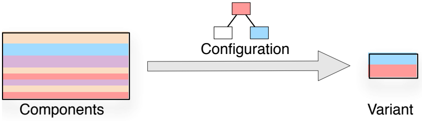
Functional decomposition (structure and process):

```
int main() {
  Weather data;
  Sink    sink;

  while(true) {

    // aquire data
    data.measure();

    // process data
    sink.process( data );

    wait();
  }
}
```



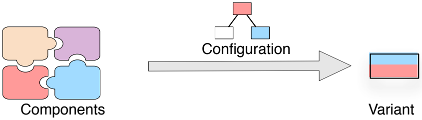
Implementation Techniques: Classification

- Decompositional Approaches



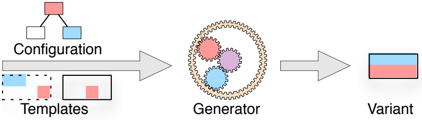
  - Text-based filtering (untyped)
  - Preprocessors

- Compositional Approaches



  - Language-based composition mechanisms (typed)
  - OOP, AOP, Templates

- Generative Approaches



  - Metamodel-based generation of components (typed)
  - MDD, C++ TMP, generators

Implementation Techniques: Goals

General

❶ Separation of concerns (SoC)

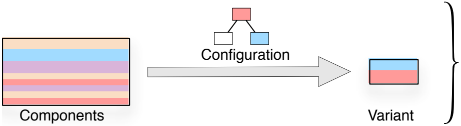
❷ Resource thriftiness

Operational

❸	Granularity	Components should be fine-grained. Each artifact should either be mandatory or dedicated to a single feature only.
❹	Economy	The use of memory/run-time expensive language features should be avoided as far as possible. Decide and bind as much as possible at generation time.
❺	Pluggability	Changing the set of optional features should not require modifications in any other part of the implementation. Feature implements should be able to "integrate themselves".
❻	Extensibility	The same should hold for new optional features, which may be available in a future version of the product line.

Implementation Techniques: The C Preprocessor

- Decompositional Approaches



  – Text-based filtering (untyped)
  – Preprocessors (**CPP**)

- Conditional compilation with the C Preprocessor (CPP) is *the* standard approach to implement static configurability [6]
  - Simplicity: the CPP "is just there"
  - Economy: CPP-usage does not involve any run-time overhead
  - Prominent especially in the domain of system software (Linux 3.2: **85000** `#ifdef` Blocks $\mapsto$ **"`#ifdef` hell"**)

I4WeatherMon (CPP): Implementation (Excerpt)

```cpp
/************************************************************/
#ifndef __Weather_h__
#define __Weather_h__

#include "util/types.h"

struct Weather {

  #ifdef cfWM_WIND
        UInt16  _w;
  #endif

  #ifdef cfWM_PRESSURE
        UInt16  _p;
  #endif

  #ifdef cfWM_TEMPERATURE
    Int8 _t1;
    UInt8 _t2;
  #endif

  #ifdef cfWM_STACK
        unsigned int _maxstack;
  #endif

};

extern Weather data;

#endif //  __Weather_h__

/************************************************************/
#include "CiAO.h"
#include "Weather.h"

// Sensor implementations
#ifdef cfWM_STACK
        #include "StackUsage.h"
#endif
#ifdef cfWM_WIND
        #include "Wind.h"
#endif

#ifdef cfWM_PRESSURE
        #include "Pressure.h"
#endif

#ifdef cfWM_TEMPERATURE
        #include "Temperature.h"
#endif

// Actor implementations, must be included after sensors
#ifdef cfWM_DISPLAY
        #include "Display.h"
#endif

#ifdef cfWM_PCCON_XML
        #include "XMLConnection.h"
#endif


// The global weather data
Weather data = {0};

// helper functions
static void wait () {
    for (volatile unsigned char i = 100; i != 0; --i)
        for (volatile unsigned char j = 100; j != 0; --j);
}

// sensor processing
inline void init_sensors() {
  #ifdef cfWM_STACK
        stack_init();
  #endif
  #ifdef cfWM_WIND
        wind_init();
  #endif

  #ifdef cfWM_PRESSURE
        pressure_init();
  #endif

  #ifdef cfWM_TEMPERATURE
        temperature_init();
  #endif
}

inline void measure() {
  #ifdef cfWM_WIND
    wind_measure();
  #endif

  #ifdef cfWM_PRESSURE
        pressure_measure();
  #endif

  #ifdef cfWM_TEMPERATURE
        temperature_measure();
  #endif

  #ifdef cfWM_STACK
        stack_measure();
  #endif
}

// actor processing
inline void init_sinks() {
  #ifdef cfWM_DISPLAY
    display_init();
  #endif

  #ifdef cfWM_PCCON_XML
        XMLCon_init();
  #endif
}

inline void process () {
  #ifdef cfWM_DISPLAY
    display_process();
  #endif

  #ifdef cfWM_PCCON_XML
        XMLCon_process();
  #endif

}
int main() {
 // initialize the CiAO system
    CiAO::start ();

    // init the sensors and actors
        init_sensors();
        init_sinks();

    asm("sei");
    DDRD |= 0x7f; // program for output

    while (true) {

            // set port D output pins to 1
            PORTD |= 0x7f;

        // measure the weather data
        measure ();

        // process the weather data somehow
        process ();

        // set port D output pins to 0
        PORTD &= ~0x7f;

        // wait for some time
        wait ();
    }

}

/************************************************************/
#ifndef __Wind_h__
#define __Wind_h__

#ifdef cfWM_WIND

#include "Weather.h"
#include "CiAO.h"
#include "String.h"

extern UInt16 _wind_counter;

inline void wind_init() {
    // load timer and allow timer interrupts
    CiAO::Timer &timer = CiAO::timer ();
    timer.period (500000L); // 100ms
    timer.start ();

    // stetup PORTD and the external event counter
    PORTD |= 0x80;
    DDRD &= ~0x80;
    CiAO::TimerCounter::external (CiAO::TimerCounter::EXT_FALL);
}

inline void wind_measure() {
        data._w = _wind_counter;
}

inline char* wind_name() {
        return "Wind";
}

inline char* wind_unit() {
        return "m/s";
}

inline void wind_stringval( char* buf ) {
        itoa_convert( data._w, buf, 4, false);
        buf[4] = '\0';
}


#endif // cfWM_WIND
#endif //  __Wind_h__

/************************************************************/
#include "CiAO.h"
#include "util/types.h"

#ifdef cfWM_WIND

// global object used for the communication with the interrupt
    handler
UInt16 _wind_counter = 0;


#include "hw/dev/timer/AVRTimer1.h"

// application defined timer interrupt handler
void ciao::AVRTimer1::tick () {
    _wind_counter = CiAO::TimerCounter::value ();
    CiAO::TimerCounter::value (0);
    CiAO::Timer &timer = CiAO::timer ();
    timer.restart ();
}

#endif

/************************************************************/
#ifndef __XMLConnection_ah__
#define __XMLConnection_ah__

#ifdef cfWM_PCCON_XML


#include "Serial.h"

void XMLCon_data (const char *name, const char *val_str);

inline void XMLCon_init() {
        Serial::init();
}

inline void XMLCon_process() {
        char val[ 5 ];

    Serial::send ("<?xml version=\"1.0\"?>\n" "<weather>\n");


 #ifdef cfWM_WIND
   wind_stringval( val );
   XMLCon_data ( wind_name(), val );
 #endif

 #ifdef cfWM_PRESSURE
   pressure_stringval( val );
   XMLCon_data ( pressure_name(), val );
 #endif

 #ifdef cfWM_TEMPERATURE
   temperature_stringval( val );
   XMLCon_data ( temperature_name(), val );
 #endif

 #ifdef cfWM_STACK
   stack_stringval( val );
   XMLCon_data ( stack_name(), val );
 #endif

   Serial::send ("</weather>\n");

}

#endif cfWM_PCCON_XML
#endif // __XMLConnection_ah__

/************************************************************/
#ifdef cfWM_PCCON_XML

#include "Serial.h"

// send a value
void XMLCon_data (const char *name, const char *val_str) {
    Serial::send ("  <data name=\"");
    Serial::send (name);
    Serial::send ("\" value=\"");
    Serial::send (val_str);
    Serial::send ("\"/>\n");
}

#endif
```

I4WeatherMon (CPP): Implementation (Excerpt)

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inline void init_sensors() {
  #ifdef cfWM_STACK
        stack_init();
  #endif
  #ifdef cfWM_WIND
        wind_init();
  #endif

  #ifdef cfWM_PRESSURE
        pressure_init();
  #endif

  #ifdef cfWM_TEMPERATURE
        temperature_init();
  #endif
}

inline void measure() {
  #ifdef cfWM_WIND
    wind_measure();
  #endif

  #ifdef cfWM_PRESSURE
        pressure_measure();
```

```
  #endif

  #ifdef cfWM_TEMPERATUR
        temperature_meas
  #endif

  #ifdef cfWM_STACK
        stack_measure();
  #endif
}

// actor processing
inline void init_sinks()
  #ifdef cfWM_DISPLAY
    display_init();
  #endif

  #ifdef cfWM_PCCON_XML
        XMLCon_init();
  #endif
}

inline void process () {
  #ifdef cfWM_DISPLAY
    display_process();
  #endif

  #ifdef cfWM_PCCON_XML
        XMLCon_process()
  #endif

}
int main() {
 // initialize the CiAO
    CiAO::start ();

    // init the sensors
        init_sensors();
        init_sinks();

    asm("sei");
    DDRD |= 0x7f; // pro

    while (true) {

            // set p
            PORTD |=

        // measure the w
        measure ();

        // process the w
        process ();

        // set port D output pins to 0
        PORTD &= ~0x7f;

        // wait for some time
        wait ();
    }

}

/**************************************************************/
#ifndef __Wind_h__
#define __Wind_h__

#ifdef cfWM_WIND

#include "Weather.h"
#include "CiAO.h"
#include "String.h"

extern UInt16 _wind_counter;

inline void wind_init() {
    // load timer and allow timer interrupts
    CiAO::Timer &timer = CiAO::timer ();
    timer.period (500000L); // 100ms
    timer.start ();

    // setup PORTD and the external event counter
    PORTD |= 0x80;
    DDRD &= ~0x80;
    CiAO::TimerCounter::external (CiAO::TimerCounter::EXT_FALL);
}

inline void wind_measure() {
        data._w = _wind_counter;
}

inline char* wind_name() {
        return "Wind";
}

inline char* wind_unit() {
        return "m/s";
```

```
  #ifdef cfWM_WIND
    wind_stringval( val );
    XMLCon_data ( wind_name(), val );
  #endif

  #ifdef cfWM_PRESSURE
    pressure_stringval( val );
    XMLCon_data ( pressure_name(), val );
  #endif

  #ifdef cfWM_TEMPERATURE
    temperature_stringval( val );
    XMLCon_data ( temperature_name(), val );
  #endif

  #ifdef cfWM_STACK
    stack_stringval( val );
    XMLCon_data ( stack_name(), val );
  #endif

    Serial::send ("</weather>\n");

}

#endif cfWM_PCCON_XML
#endif // __XMLConnection_ah__

/*****************************
#ifdef cfWM_PCCON_XML

#include "Serial.h"

// send a value
void XMLCon_data (const char *name,
    Serial::send ("  <data name=\""
    Serial::send (name);
    Serial::send ("\" value=\"");
    Serial::send (val_str);
    Serial::send ("\"/>\n");
}

#endif
```

```
struct Weather {

  #ifdef cfWM_WIND
        UInt16  _w;
  #endif

  #ifdef cfWM_PRESSURE
        UInt16  _p;
  #endif

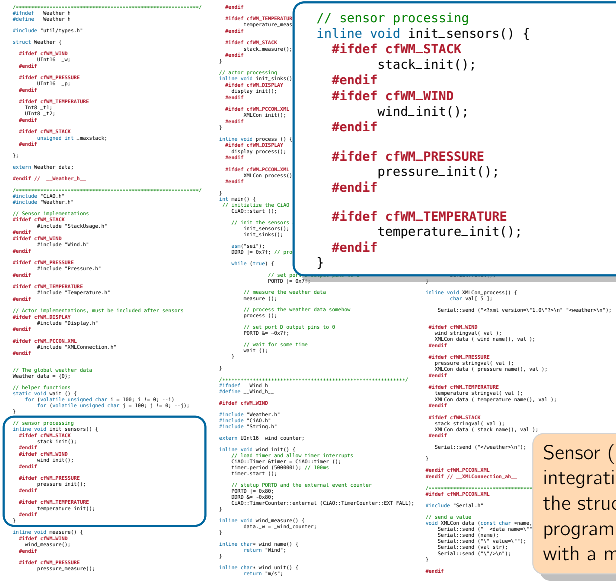
  #ifdef cfWM_TEMPERATURE
    Int8 _t1;
    UInt8 _t2;
  #endif

  #ifdef cfWM_STACK
        unsigned int _maxstack;
  #endif

};
```

Sensor integration cross-cuts the central data structure, an interaction with a mandatory feature.

I4WeatherMon (CPP): Implementation (Excerpt)



```
// sensor processing
inline void init_sensors() {
  #ifdef cfWM_STACK
        stack_init();
  #endif
  #ifdef cfWM_WIND
        wind_init();
  #endif

  #ifdef cfWM_PRESSURE
        pressure_init();
  #endif

  #ifdef cfWM_TEMPERATURE
        temperature_init();
  #endif
}
```

Sensor (and actuator) integration both crosscut the structure of the main program, an interaction with a mandatory feature.

I4WeatherMon (CPP): Implementation (Excerpt)

```
inline void XMLCon_process() {
        char val[ 5 ];

    Serial::send ("<?xml version=\"1.0\"?>\n" "<weather>\n");


 #ifdef cfWM_WIND
   wind_stringval( val );
   XMLCon_data ( wind_name(), val );
 #endif

 #ifdef cfWM_PRESSURE
   pressure_stringval( val );
   XMLCon_data ( pressure_name(), val );
 #endif

 #ifdef cfWM_TEMPERATURE
   temperature_stringval( val );
   XMLCon_data ( temperature_name(), val );
 #endif

 #ifdef cfWM_STACK
   stack_stringval( val );
   XMLCon_data ( stack_name(), val );
 #endif

   Serial::send ("</weather>\n");

}
```

```
#endif
#ifdef cfWM_WIND
        wind_init();
#endif

#ifdef cfWM_PRESSURE
        pressure_init();
#endif

#ifdef cfWM_TEMPERATURE
        temperature_init();
#endif
}

inline void measure() {
#ifdef cfWM_WIND
    wind_measure();
#endif

#ifdef cfWM_PRESSURE
        pressure_measure();
```

```
inline void wind_init() {
    // load timer and allow timer interrupts
    CiAO::Timer &timer = CiAO::timer ();
    timer.period (500000L); // 100ms
    timer.start ();

    // setup PORTD and the external event counter
    PORTD |= 0x80;
    DDRD &= ~0x80;
    CiAO::TimerCounter::external (CiAO::TimerCounter::EXT_FALL);
}

inline void wind_measure() {
        data._w = _wind_counter;
}

inline char* wind_name() {
        return "Wind";
}

inline char* wind_unit() {
        return "m/s";
```

```
}

inline void wind_stringval( char* buf ) {
        itoa_convert( data._w, buf, 4, false);
        buf[4] = '\0';
}

#endif // cfWM_WIND
#endif //  __Wind_h__

/************************************************************/
#include "CiAO.h"
#include "util/types.h"

#ifdef cfWM_WIND

// global object used for the communication with the interrupt
    handler
UInt16 _wind_counter = 0;


#include "hw/dev/timer/AVRTimer1.h"

// application defined timer interrupt handler
void ciao::AVRTimer1::tick () {
    _wind_counter = CiAO::TimerCounter::value ();
    CiAO::TimerCounter::value (0);
    CiAO::Timer &timer = CiAO::timer ();
    timer.restart ();
}

#endif

/************************************************************/
#ifndef __XMLConnection_ah__
#define __XMLConnection_ah__

#ifdef cfWM_PCCON_XML


#include "Serial.h"

void XMLCon_data (const char *name, const char *val_str);

inline void XMLCon_init() {
        Serial::init();
}

inline void XMLCon_process() {
        char val[ 5 ];

    Serial::send ("<?xml version=\"1.0\"?>\n" "<weather>\n");


 #ifdef cfWM_WIND
   wind_stringval( val );
   XMLCon_data ( wind_name(), val );
 #endif

 #ifdef cfWM_PRESSURE
   pressure_stringval( val );
   XMLCon_data ( pressure_name(), val );
 #endif

 #ifdef cfWM_TEMPERATURE
   temperature_stringval( val );
   XMLCon_data ( temperature_name(), val );
 #endif

 #ifdef cfWM_STACK
   stack_stringval( val );
   XMLCon_data ( stack_name(), val );
 #endif

   Serial::send ("</weather>\n");

}

#endif cfWM_PCCON_XML
#endif // __XMLConnection_ah__

/**********************************
#ifdef cfWM_PCCON_XML

#include "Serial.h"

// send a value
void XMLCon_data (const char *name,
    Serial::send ("   <data name=\""
    Serial::send (name);
    Serial::send ("\" value=\"");
    Serial::send (val_str);
    Serial::send ("\"/>\n");
}

#endif
```

Sensor integration also crosscuts actuator code, an **interaction between optional features!**

I4WeaterMon (CPP): Evaluation

General

❶ Separation of concerns (SoC) ✘

❷ Resource thriftiness ✔

Operational

❸ Granularity (✔)

- Components implement only the functionality of a single feature, but contain integration code for other optional features.

❹ Economy ✔

- All features is bound at compile time.

❺ Pluggability ✘

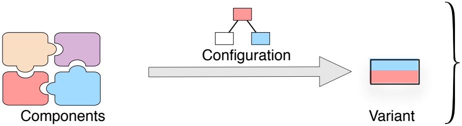
- Sensor integration crosscuts main program and actuator implementation.

❻ Extensibility ✘

- New actuators require extension of main program.
- New sensors require extension of main program and existing actuators.

Implementation Techniques: OOP

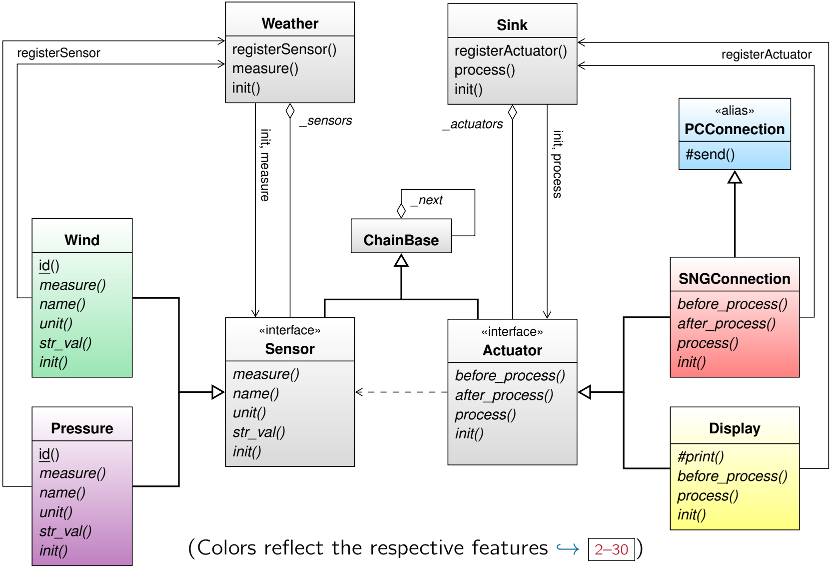
- Compositional Approaches



  – Language-based composition mechanisms (typed)
  – **OOP**, AOP, Templates

- Object-oriented programming languages provide means for loose coupling by generalization and OO design patterns
  - Interfaces
    $\leadsto$ type substitutability (optional/alternative features)
  - Observer-Pattern
    $\leadsto$ quantification (cumulative feature groups)
  - Implicit code execution by global instance construction
    $\leadsto$ self integration (optional features)

I4WeatherMon (OOP): Design (Excerpt)



(Colors reflect the respective features ↪ 2–30)

I4WeaterMon (OOP): Evaluation

General

❶ Separation of concerns (SoC) ✔

❷ Resource thriftiness ?

Operational

❸ Granularity ✔

- Every component is either a base class or implements functionality of a single feature only.

❹ Economy (✔)

- Run-time binding and run-time type information is used only where necessary to achieve SoC.

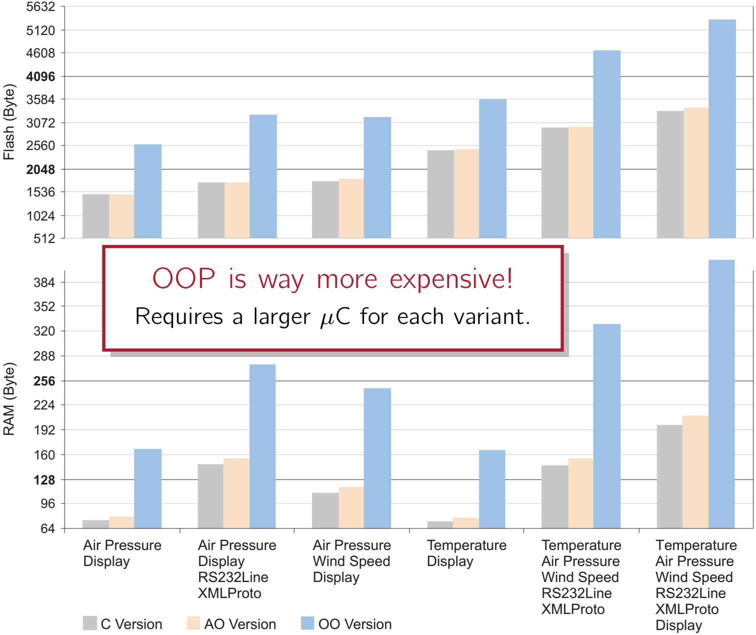
❺ Pluggability ✔

- Sensors and actuators integrate themselve by design patterns and global instance construction.

❻ Extensibility ✔

- "Plug & Play" of sensor and actuator implementations.

I4WeaterMon: CPP vs. OOP – Footprint



OOP is way more expensive!

Requires a larger μC for each variant.

I4WeaterMon: CPP vs. OOP – Footprint

variant	version	text	data	bss	stack	= flash	= RAM	time (ms)
Air Pressure, Display	**C**	*1392*	*30*	*7*	*34*	*1422*	*71*	*1.21*
	AO	*1430*	*30*	*10*	*38*	*1460*	*78*	*1.21*
	OO	*2460*	*100*	*22*	*44*	*2560*	*166*	*1.29*
Air Pressure, Display, RS232Line, XMLProto	**C**	*1578*	*104*	*7*	*34*	*1682*	*145*	*60.40*
	AO	*1622*	*104*	*12*	*38*	*1726*	*154*	*59.20*
	OO	*3008*	*206*	*26*	*44*	*3214*	*276*	*60.80*
Air Pressure, Wind Speed, Display	**C**	*1686*	*38*	*14*	*55*	*1724*	*107*	*2.96*
	AO	*1748*	*38*	*18*	*61*	*1786*	*117*	*2.96*
	OO	*3020*	*146*	*33*	*65*	*3166*	*244*	*3.08*
Temperature, Display	**C**	*2378*	*28*	*8*	*34*	*2406*	*70*	*1.74*
	AO	*2416*	*28*	*11*	*38*	*2444*	*77*	*1.73*
	OO	*3464*	*98*	*23*	*44*	*3562*	*165*	*1.82*
Temperature, Wind Speed, Air Pressure, RS232Line, XMLProto	**C**	*2804*	*90*	*17*	*35*	*2894*	*142*	*76.40*
	AO	*2858*	*90*	*23*	*41*	*2948*	*154*	*76.40*
	OO	*4388*	*248*	*39*	*41*	*4636*	*328*	*76.40*
Temperature, Wind Speed, Air Pressure, RS232Line, XMLProto, Display	**C**	*3148*	*122*	*17*	*57*	*3270*	*196*	*79.60*
	AO	*3262*	*122*	*24*	*63*	*3384*	*209*	*77.60*
	OO	*5008*	*300*	*44*	*67*	*5308*	*411*	*80.00*

Implementation Techniques: Summary

- CPP: minimal hardware costs – but no separation of concerns
- OOP: separation of concerns – but high hardware costs
- OOP cost drivers
  - Late binding of functions (virtual functions)
    - Calls cannot be inlined ($\leadsto$ *memory* overhead for small methods)
    - Virtual function tables
    - Compiler always generates constructors (for vtable initialization)
    - Dead code elimination less effective
  - Dynamic data structures
  - Static instance construction
    - Generation of additional initialization functions
    - Generation of a global constructor table
    - Additional startup-code required

Implementation Techniques: Summary

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  - Static instance construction
    - Generation of additional initializatior
    - Generation of a global constructor t
    - Additional startup-code required

Root of the problem:
With OOP we have to use **dynamic** language concepts to achieve loose coupling of **static** decisions.
⇝ **AOP** as an alternative.

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