

Konfigurierbare Systemsoftware (KSS)

VL 2 – Software Product Lines

Daniel Lohmann

Lehrstuhl für Informatik 4
Verteilte Systeme und Betriebssysteme

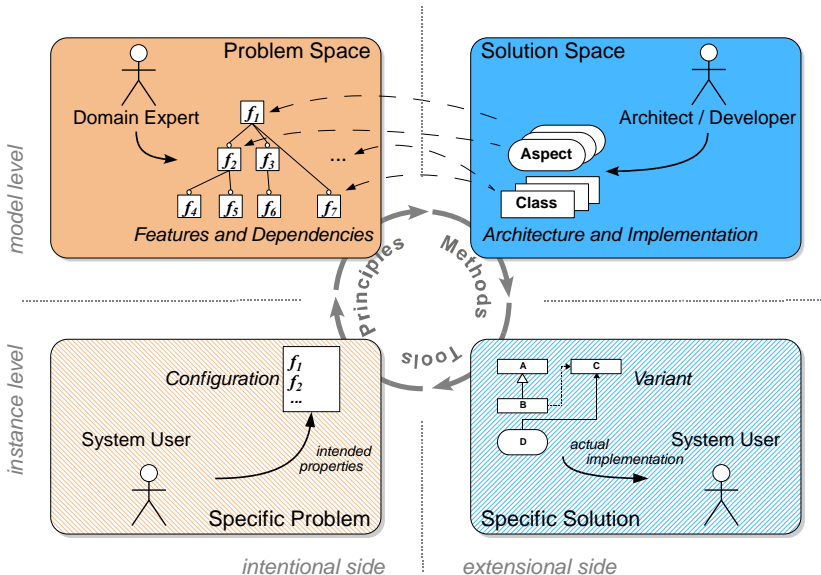
Friedrich-Alexander-Universität
Erlangen-Nürnberg

SS 15 – 2015-04-27

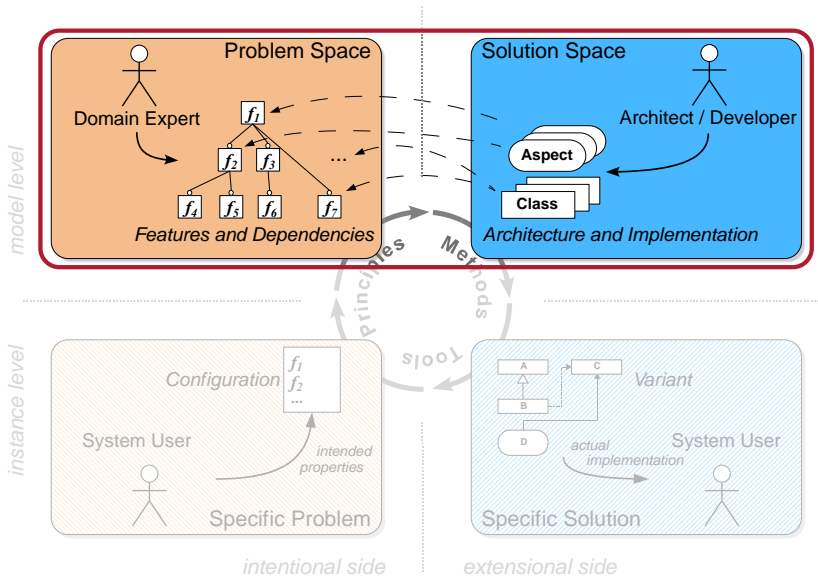
http://www4.informatik.uni-erlangen.de/Lehre/SS15/V_KSS



About this Lecture



About this Lecture



- 2.1 Motivation: The Quest for Variety
- 2.2 Introduction: Software Product Lines
- 2.3 Case Study: i4Weathermon
- 2.4 Problem Space
- 2.5 Solution Space
- 2.6 References



2.1 Motivation: The Quest for Variety

Model Car Industry

Challenges

2.2 Introduction: Software Product Lines

2.3 Case Study: i4Weathermon

2.4 Problem Space

2.5 Solution Space

2.6 References



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: **10^{20}** possible variants
- BMW: **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!

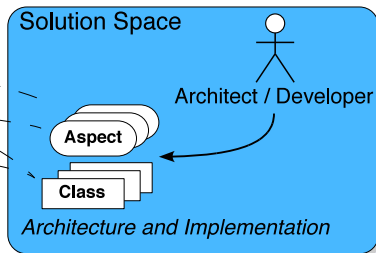
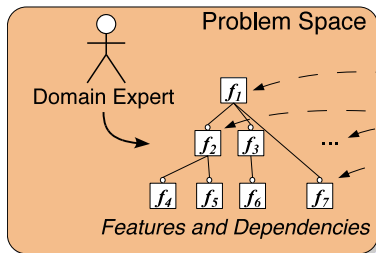
Typical Configurable Operating Systems...



5000 features



14000 features



- 1 How to **identify** the actually desired variability?
- 2 How to **express** the intended variability?
- 3 How to **implement** this variability in the code?
- 4 How to **map** variability options to the code?

2.1 Motivation: The Quest for Variety

2.2 Introduction: Software Product Lines

Terms and Definitions

SPL Development Process

Our Understanding of SPLs

2.3 Case Study: i4Weathermon

2.4 Problem Space

2.5 Solution Space

2.6 References



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**



Definition: (Software) Product Line, Feature

Product Line (Withey)

(Definition 1)

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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

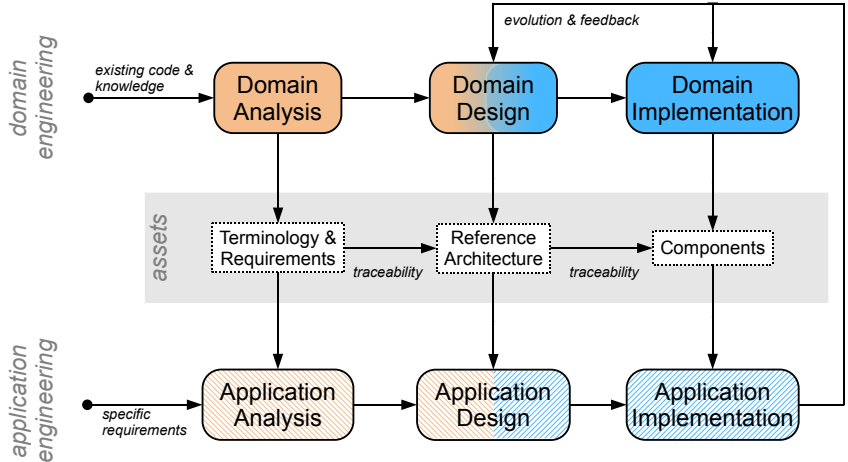
(Definition 4)

“ 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 \Rightarrow Software Product Line
 - However, according to the definitions, the viewpoint is different
 - Program family: defined by similarity between programs \rightarrow Solutions
 - SPL: defined by similarity between requirements \rightarrow Problems
- \Rightarrow A program family **implements** a software product line
- In current literature, however, both terms are used synonymously
 - Program Family \Leftrightarrow Software Product Line





application engineering → **tailoring**



Configurability

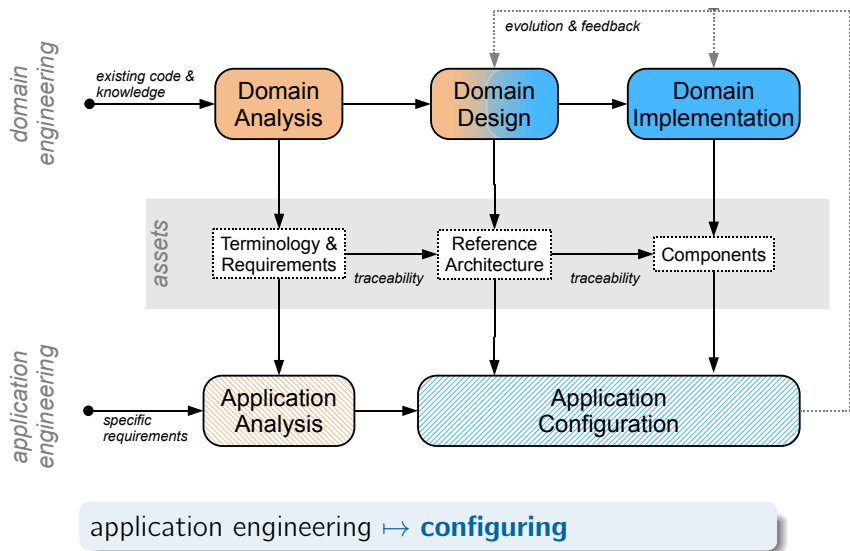
(Definition 5)

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

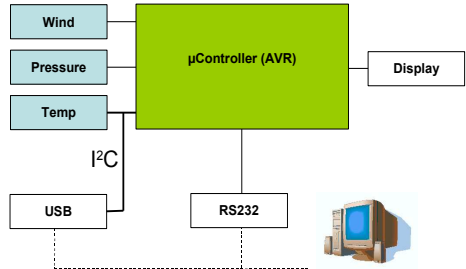


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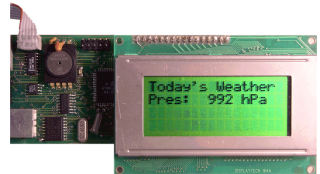
■ A typical embedded system

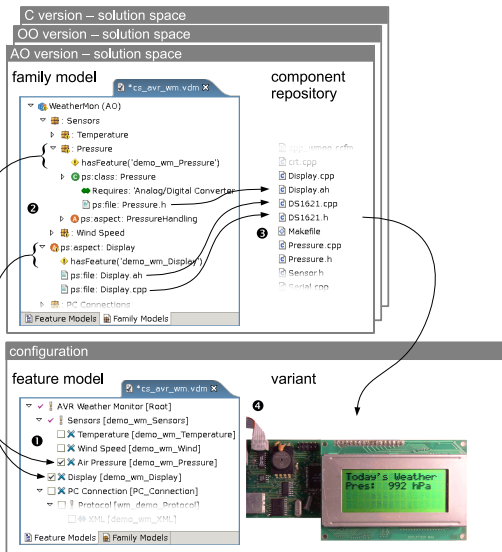
- Several, optional **sensors**
 - Wind
 - Air Pressure
 - Temperature
- Several, optional **actuators** (here: output devices)
 - LCD
 - PC via RS232
 - PC via USB



■ To be implemented as a product line

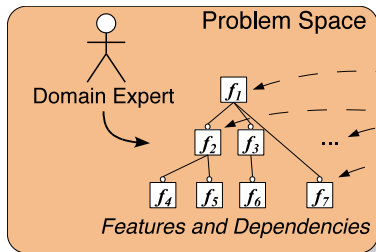
- **Barometer**: Pressure + Display
- **Thermometer**: Temperature + Display
- **Deluxe**: Temperature + Pressure + Display + PC-Connection
- **Outdoor**: <as above> + Wind
- ...



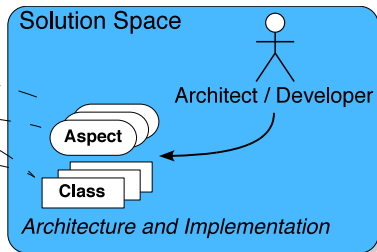


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- 2.4 Problem Space**
 - Domain Analysis
 - Feature Modelling
- 2.5 Solution Space
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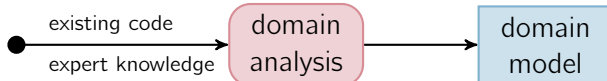




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- 3 How to **implement** this variability in the code?
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■ Domain Scoping

- 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

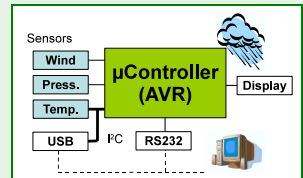
- **Domain definition** specifies the scope of the domain
 - Examples and counter examples
 - Rules for inclusion/exclusion of systems or features
- **Domain glossary** defines the vocabulary of the domain
 - Naming of features and concepts
- **Concept models** describe relevant concepts of the domain
 - 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 μ C and shall not be changed after delivery.
- The i4WeatherMon shall be usable with all versions of the **PC Weather** client software.
- ...



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 i4WeatherMon 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**.
- ...

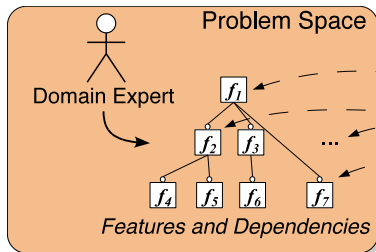


I4WeatherMon: Domain Model (simplified)

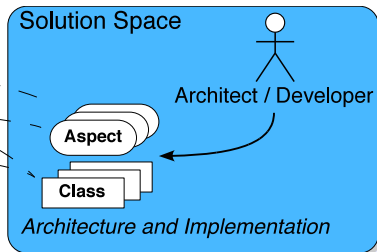
Concept Models: i4WeatherMon

- **XML Protocol:** The following DTD specifies the format used for data transmission over a **PC Connection**:
`<!ELEMENT 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** ...
- ...





- 1 How to **identify** the actually desired variability?
- 2 How to **express** the intended variability?



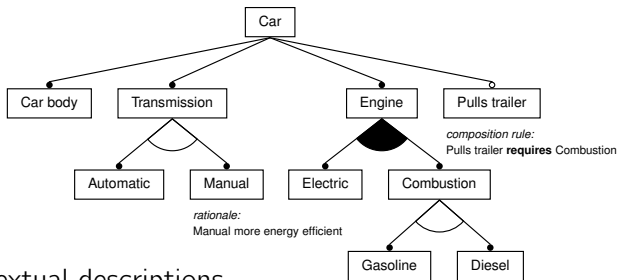
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Feature Models

- 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, ...

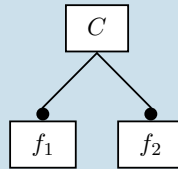


Feature Diagrams – Language

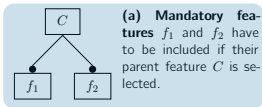
Syntactical Elements

The filled dot ● indicates a mandatory feature:

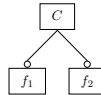
$$\mathcal{V} = \{(C, f_1, f_2)\}$$



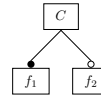
(a) **Mandatory features** f_1 and f_2 have to be included if their parent feature C is selected.



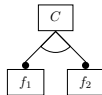
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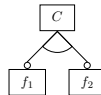
(b) **Optional features** f_1, f_2 can be included if their parent feature C is selected.



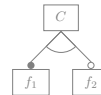
(c) **Mandatory feature** f_1 has to be included, **optional feature** f_2 can be included if their parent feature C is selected.



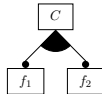
(d) Exactly one **alternative feature** f_1 or f_2 has to be included if the group's parent feature C is selected.



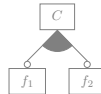
(e) At most one **optional alternative feature** f_1 or f_2 can be included if the group's parent feature C is selected.



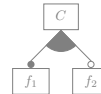
(f) *Not used.*
Equivalent to (e).



(g) At least one **cumulative feature** f_1, f_2 has to be included if the group's parent feature C is selected.



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



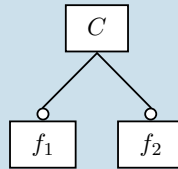
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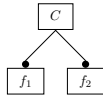
Syntactical Elements

A shallow dot \circ indicates an optional feature:

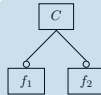
$$\mathcal{V} = \{(C), (C, f_1), (C, f_2), (C, f_1, f_2)\}$$



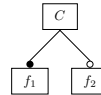
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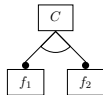
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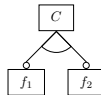
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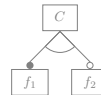
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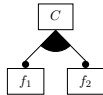
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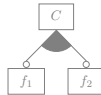
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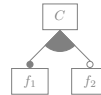
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 Equivalent to (e).



(g) At least one cumulative feature f_1, f_2 has to be included if the group's parent feature C is selected.



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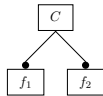
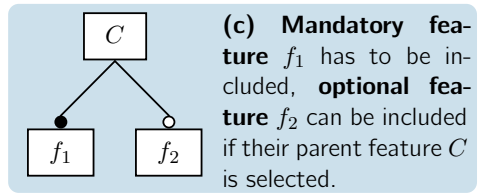
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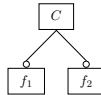
Syntactical Elements

Of course, both can be combined:

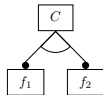
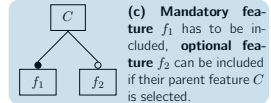
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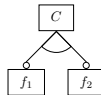
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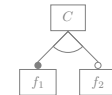
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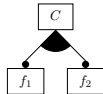
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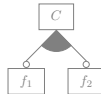
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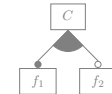
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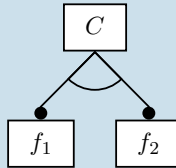
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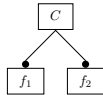
Syntactical Elements

The shallow arc \triangle depicts a group of alternative features:

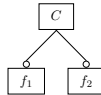
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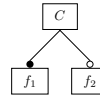
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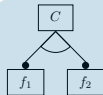
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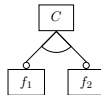
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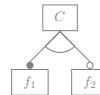
(c) **Mandatory feature** f_1 has to be included, **optional feature** f_2 can be included if their parent feature C is selected.



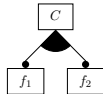
(d) Exactly one **alternative feature** f_1 or f_2 has to be included if the group's parent feature C is selected.



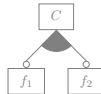
(e) At most one **optional alternative feature** f_1 or f_2 can be included if the group's parent feature C is selected.



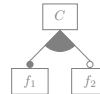
(f) *Not used. Equivalent to (e).*



(g) At least one **cumulative feature** f_1, f_2 has to be included if the group's parent feature C is selected.



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



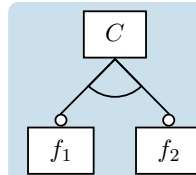
(i) *Not used. Equivalent to (b).*



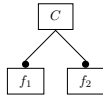
Syntactical Elements

The shallow arc \triangle depicts a group of alternative features:

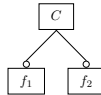
$$\mathcal{V} = \{(C), (C, f_1), (C, f_2)\}$$



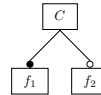
(e) At most one **optional alternative feature** f_1 or f_2 can be included if the group's parent feature C is selected.



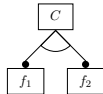
(a) **Mandatory features** f_1 and f_2 have to be included if their parent feature C is selected.



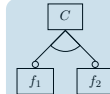
(b) **Optional features** f_1, f_2 can be included if their parent feature C is selected.



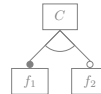
(c) **Mandatory feature** f_1 has to be included, **optional feature** f_2 can be included if their parent feature C is selected.



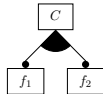
(d) Exactly one **alternative feature** f_1 or f_2 has to be included if the group's parent feature C is selected.



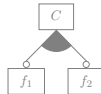
(e) At most one **optional alternative feature** f_1 or f_2 can be included if the group's parent feature C is selected.



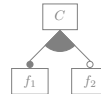
(f) *Not used.*
Equivalent to (e).



(g) At least one **cumulative feature** f_1, f_2 has to be included if the group's parent feature C is selected.



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

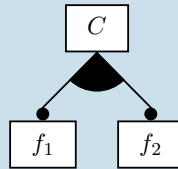


(i) *Not used.*
Equivalent to (b).

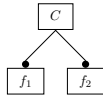


Syntactical Elements

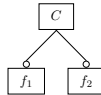
The filled arc \blacktriangle depicts a group of cumulative features: $\mathcal{V} = \{(C, f_1), (C, f_2), (C, f_1, f_2)\}$



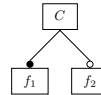
(g) At least one **cumulative feature** f_1, f_2 has to be included if the group's parent feature C is selected.



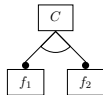
(a) **Mandatory features** f_1 and f_2 have to be included if their parent feature C is selected.



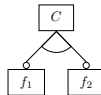
(b) **Optional features** f_1, f_2 can be included if their parent feature C is selected.



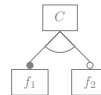
(c) **Mandatory feature** f_1 has to be included, **optional feature** f_2 can be included if their parent feature C is selected.



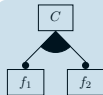
(d) Exactly one **alternative feature** f_1 or f_2 has to be included if the group's parent feature C is selected.



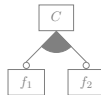
(e) At most one **optional alternative feature** f_1 or f_2 can be included if the group's parent feature C is selected.



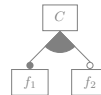
(f) *Not used.*
Equivalent to (e).



(g) At least one **cumulative feature** f_1, f_2 has to be included if the group's parent feature C is selected.



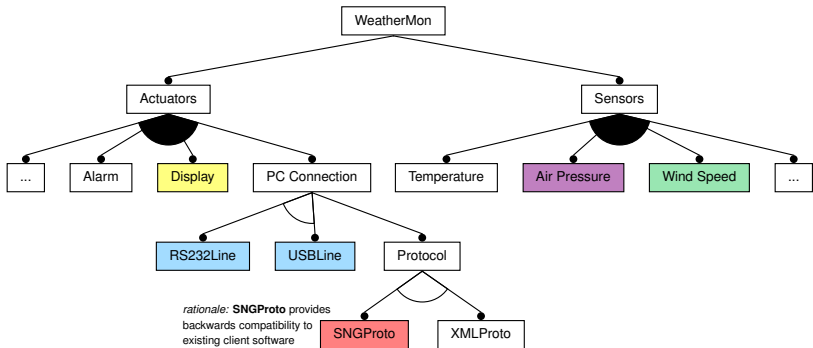
(h) *Not used.*
Equivalent to (b).

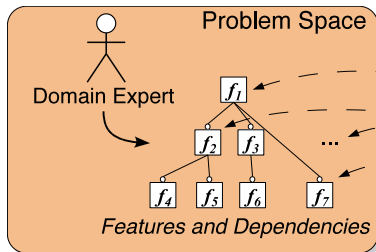


(i) *Not used.*
Equivalent to (b).

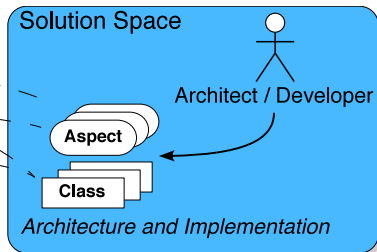


I4WeatherMon: Feature Model





- 1 How to **identify** the actually desired variability?
- 2 How to **express** the intended variability?



- 3 How to **implement** this variability in the code?
- 4 How to **map** variability options to the code?

2.1 Motivation: The Quest for Variety

2.2 Introduction: Software Product Lines

2.3 Case Study: i4Weathermon

2.4 Problem Space

2.5 Solution Space

- Reference Architecture

- Implementation Techniques Overview

- Variability Implementation with the C Preprocessor

- Variability Implementation with OOP (C++)

- Evaluation and Outlook

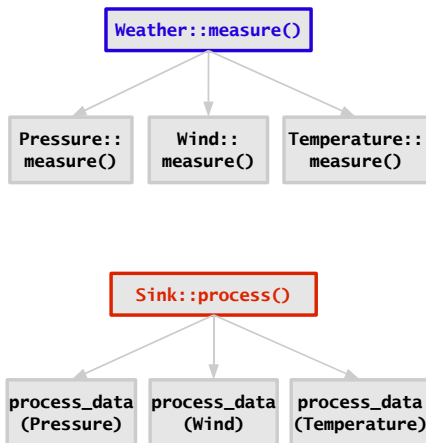
2.6 References



I4WeatherMon: Reference Architecture

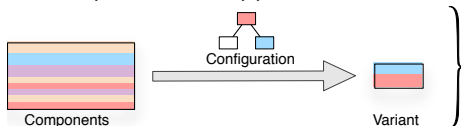
Functional decomposition (structure and process):

```
int main() {  
    Weather data;  
    Sink    sink;  
  
    while(true) {  
        // aquire data  
        data.measure();  
  
        // process data  
        sink.process( data );  
  
        wait();  
    }  
}
```



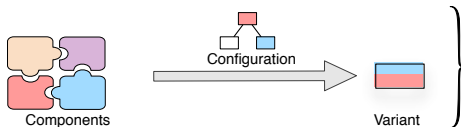
Implementation Techniques: Classification

■ Decompositional Approaches



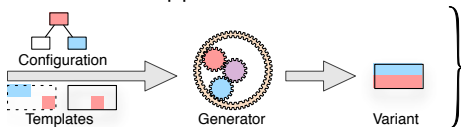
- Text-based filtering (untyped)
- Preprocessors

■ Compositional Approaches



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

■ Generative Approaches



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



General

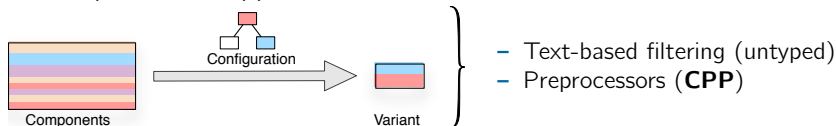
- ① Separation of concerns (SoC)
- ② Resource thriftiness

Operational

- ③ **Granularity** Components should be fine-grained. Each artifact should either be mandatory or dedicated to a single feature only.
- ④ **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.
- ⑤ **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”.
- ⑥ **Extensibility** The same should hold for new optional features, which may be available in a future version of the product line.



■ Decompositional Approaches



- 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**”)





© dl



```

//define CPU_TEMPERATURE
temperature_max;

//define CPU_STACK
stack_measure();
#endif

// after processing
inline void init_stack()
{
    //define CPU_STACK
    display_process();
}

//define CPU_PCCOR_XML
XML_Cor_processes();

inline void process () {
    //define CPU_DISPLAY
    display_process();
}

//define CPU_PCCOR_XML
XML_Cor_processes();
}

int main() {
    // initialize the C140
    C140::start();

    // init the sensors
    //initiateLine();
    init_sinks();
    sen["test"];
    while (true) { // pro
        while (true) { // set p
            // measure the w
            PORTB |= 0x01;
            // process the w
            process ();
            // set port D to 0
            PORTD = 0x00;
            // wait for same
            wait ();
        }
    }
}

//.....
//define Wind_h
//define "C140.h"
extern WindH_Wind_cor
inline void wind_init()
{
    // load timer and at
    // timer:period
    timer-period (1500000);
    timer-start();
}

// define Wind_h and
PORTB |= 0x00;
PORTD = 0x00;
C140::TimerCounter();

inline void wind_measure
{
    data_w = wind;
}

inline char wind_init()

```

[illegible]

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



```
// sensor pin definitions
#define CFW_TEMPERATURE // sensor pin
                           // temperature meas
#define CFW_STACK        // sensor pin
                           // stack measure
#define CFW_WIND          // sensor pin
                           // wind speed
#define CFW_PRESS         // sensor pin
                           // pressure

// actor processing
inline void inst_sink0() {
    #ifndef CFW_DISPLAY
        display.process();
    #endif
    #ifndef CFW_PCCHN_INL
        JBLCon_inl();
    #endif
}

inline void process () {
    #ifndef CFW_DISPLAY
        display.process();
    #endif
    #ifndef CFW_PCCHN_INL
        JBLCon_process();
    #endif
}

int main() {
    // initializing the CIAO
    CIAO::start();

    // init the sensors
    inst_sensors();
    inst_sinks();

    const "init";
    SONG = 0; // pro

    while (true) {
        // set port 0
        PORT0 [= 0];

        // measure the weather data
        measure ();

        // process the weather data somehow
        process ();

        // set port 0 output pins to 0
        PORT0A [= 0];

        // wait for some time
        wait ();
    }
}

// =====
// Wind
// =====
#include "Weather.h"
#include "CIAO.h"
#include "String.h"

extern U32to16_wind_counter;

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

    // startup PORT0 and the external event counter
    PORT0 [= 0];
    SONG = 0;
    CIAO::CIAO::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";
}
```

```
// 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 XMCL_ConnProcess() {
    char val[ 5 ];

    Serial::send ("<?xml version='1.0'><b>1</b></?xml>");

}

//if the cMm_WIND
wind_stringval[] val ;
XMCL_Conn_data ( wind_name[] , val );
//endif

//if the cMm_PRESSURE
pressure_stringval[] val ;
XMCL_Conn_data ( pressure_name[] , val );
//endif

//if the cMm_TEMPERATURE
temperature_stringval[] val ;
XMCL_Conn_data ( temperature_name[] , val );
//endif

//if the cMm_STACK
stack_stringval[] val ;
XMCL_Conn_data ( stack_name[] , val );
//endif

Serial::send ("<?xml>");
}

//if the cMm_PCCONN_INT
//if ..._XMCLConnection_ab...

//.....
//if the cMm_PCCONN_INT
//.....

#include "Serial.h"

// send a value
void XMCL_Conn_data (const char *name,
    Serial::send (name+"=");
    Serial::send (name);
    Serial::send ("\" value\"");
    Serial::send (val, str);
    Serial::send ("\"/>");
}

//endif

```

© dl

14WeatherMon (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 cMcu_WIND
    wind_init();
#endif

#ifdef cMcu_PRESSURE
    pressure_init();
#endif

#ifdef cMcu_TEMPERATURE
    temperature_init();
#endif
}

inline void wind_measure() {
    ifof cMcu_WIND {
        wind_measure();
    }
}

#ifdef cMcu_PRESSURE
    pressure_measure();
#endif

    inline void wind_init() {
        // load timer and allow timer interrupts
        CIAD:TimerCounter = CIAD:timer (1);
        timer-period (500000); // 100ms
        timer-start ();

        // setup PORTD and the external event counter
        PORTD = 0x00;
        DDSD = 0x00;
        CIAD:TimerCounter=external (CIAD:TimerCounter:EXT_FALL);

        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 // CPM_WIND

//endif // _WIND_
//=====
#include "CM2.h"
//=====
//endif // CPM_TYPES_H
//endif CPM_WIND

// Global object used for the communication with the interrupt
handler
uint16 wind_counter = 0;

#include "hwDef/Timer/AWRTimer1.h"
// application defined timer interrupt handler
void cpm_AWRTimer1_tick () {
    wind_counter = CMO:TimerCounter;value ();
    CMIO:TimerCounter;value (0);
    CMIO:Timer_drammer = CMO:timer ();
    timer_restart ();
}

//endif

//=====
//endif _XMC_CONNECTION_
//define XMC_Connection_ah_
//endif CPM_PCCON_XMC

#include "CMA.h"

void XMCCon_data (const char *name, const char *val, str);
inline void XMCCon_init () {
    Serial: init();
}

//inline void XMCCon_process () {
    char val[ 5 ];
    Serial: read ( "CMA version:1.0\n" >> "CMAweather\n");

    //endif CPM_WIND
    wind_stringval( val );
    XMCCon_data ( wind_name(), val );

    //endif CPM_PRESSURE
    pressure_stringval( val );
    XMCCon_data ( pressure_name(), val );
    //endif

    //endif CPM_TEMPERATURE
    temperature_stringval( val );
    XMCCon_data ( temperature_name(), val );
    //endif

    //endif CPM_STACK
    stack_stringval( val );
    XMCCon_data ( stack_name(), val );
    //endif

    Serial: send ( "<CMAweather\n");
}

```

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



General

- ① Separation of concerns (SoC)
- ② Resource thriftiness

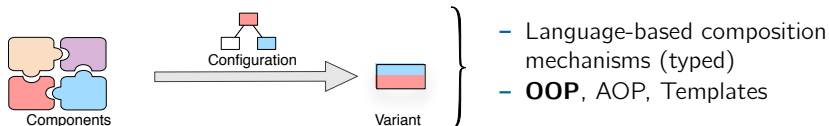


Operational

- ③ Granularity (✓)
 - Components implement only the functionality of a single feature, but contain integration code for other optional features.
- ④ Economy ✓
 - All features is bound at compile time.
- ⑤ Pluggability ✗
 - Sensor integration crosscuts main program and actuator implementation.
- ⑥ Extensibility ✗
 - New actuators require extension of main program.
 - New sensors require extension of main program and existing actuators.



■ Compositional Approaches

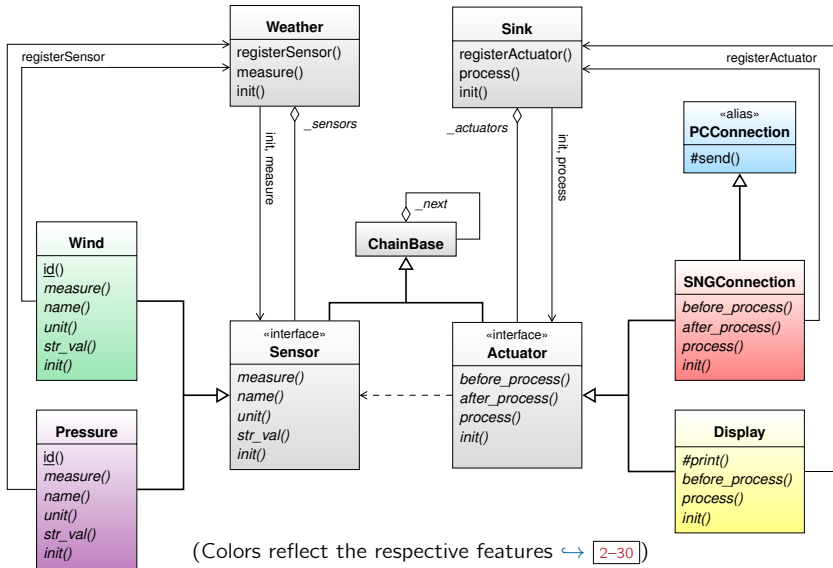


■ Object-oriented programming languages provide means for loose coupling by generalization and OO design patterns

- Interfaces
 - ↪ type substitutability (optional/alternative features)
- Observer-Pattern
 - ↪ quantification (cumulative feature groups)
- Implicit code execution by global instance construction
 - ↪ self integration (optional features)



I4WeatherMon (OOP): Design (Excerpt)



General

- ① Separation of concerns (SoC)
- ② Resource thriftiness



Operational

③ Granularity

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



④ Economy

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



⑤ Pluggability

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

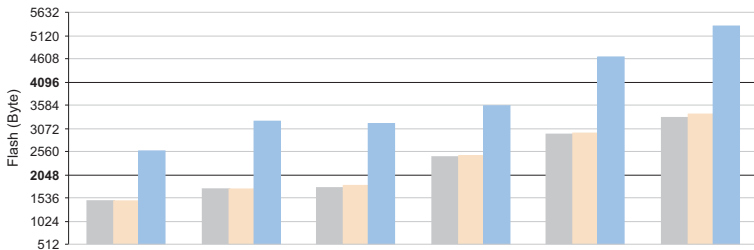


⑥ Extensibility

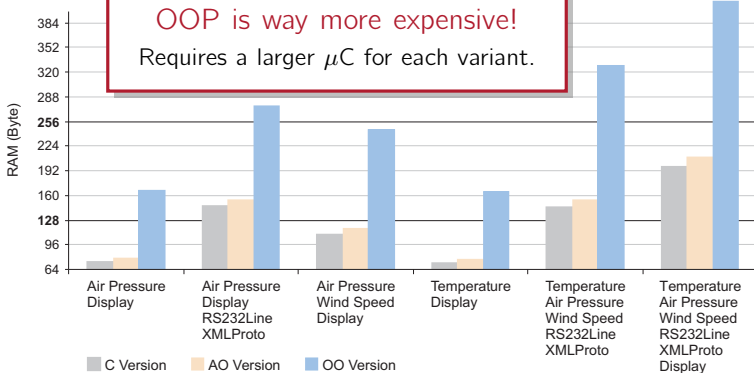
- “Plug & Play” of sensor and actuator implementations.



I4WeaterMon: CPP vs. OOP – Footprint



OOP is way more expensive!
Requires a larger μ C 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



- 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 (↪ *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

- 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 (↪ *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 code
 - Generation of a global constructor table
 - 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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