The COSA Framework

A Cognitive System Architecture with its implementation based on a CORBA-wrapped SOAR process

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Who are we ?

Who are we ?

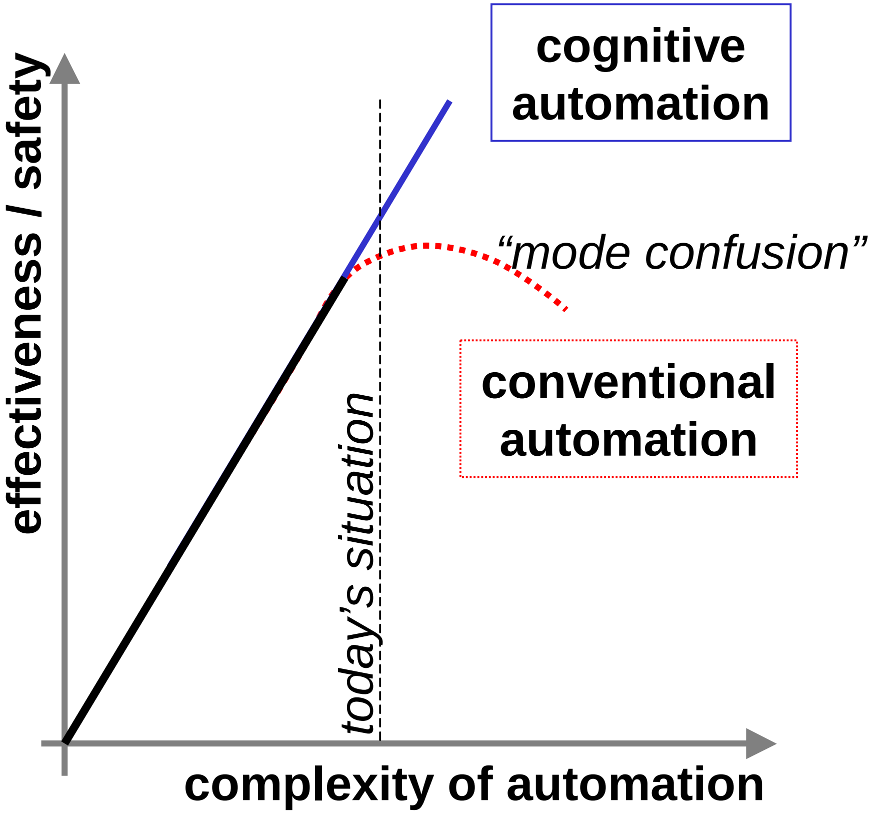
- **Institut für Systemdynamik und Flugmechanik Universität der Bundeswehr München, Germany**
- **Research objectives**
  - *flight guidance and control*
  - *“Human Engineering”, not Psychology*
  - *top down (architecture), not bottom up (sensors)*
  - *cognitive systems (<u>assistants</u>, tutors, UAV, etc.)*
  - *architecture with target system in mind*
- **first contact with SOAR one year ago**
  - *while searching for knowledge processors via the web*
  - *but not much experience so far (focus on architecture)*

What are we doing ?

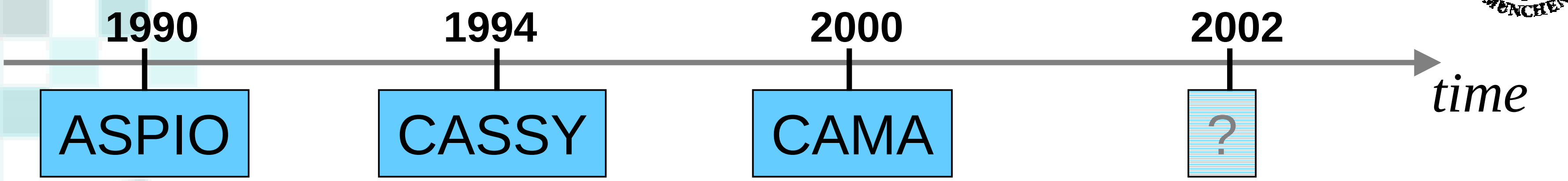
Motivation

- **Increasing:**
  - ↳ *system complexity*
  - ↳ *automated functions*
  - ↳ *complexity of situation*
  - ↳ *complexity of mission*
  - ↳ *complex planning and decisions*

- **but:**
  constant crew resources



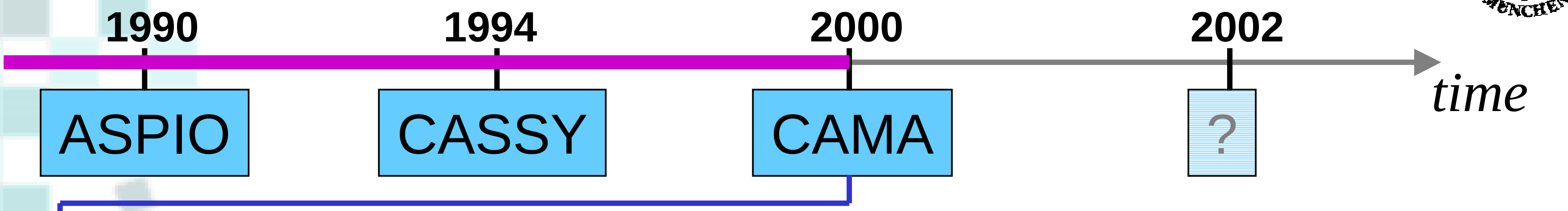
System Evolution



- **research yielded operational systems**

- **systems improved over time in ...**
  - ↳ *software development*
  - ↳ *architecture*
  - ↳ *functionality*

System Evolution - CAMA



Crew Assistant Military Aircraft

- **functional extension of CASSY** (for military transport missions)
  - ↳ *modular architecture*
  - ↳ *central situation representation*
  - ↳ *based on CASSY, coded in C and C++*
- **successfully flight tested in 2000**
- **great acceptance by pilots**

... but:
grown over years and now hard to maintain or extend.

Analysis

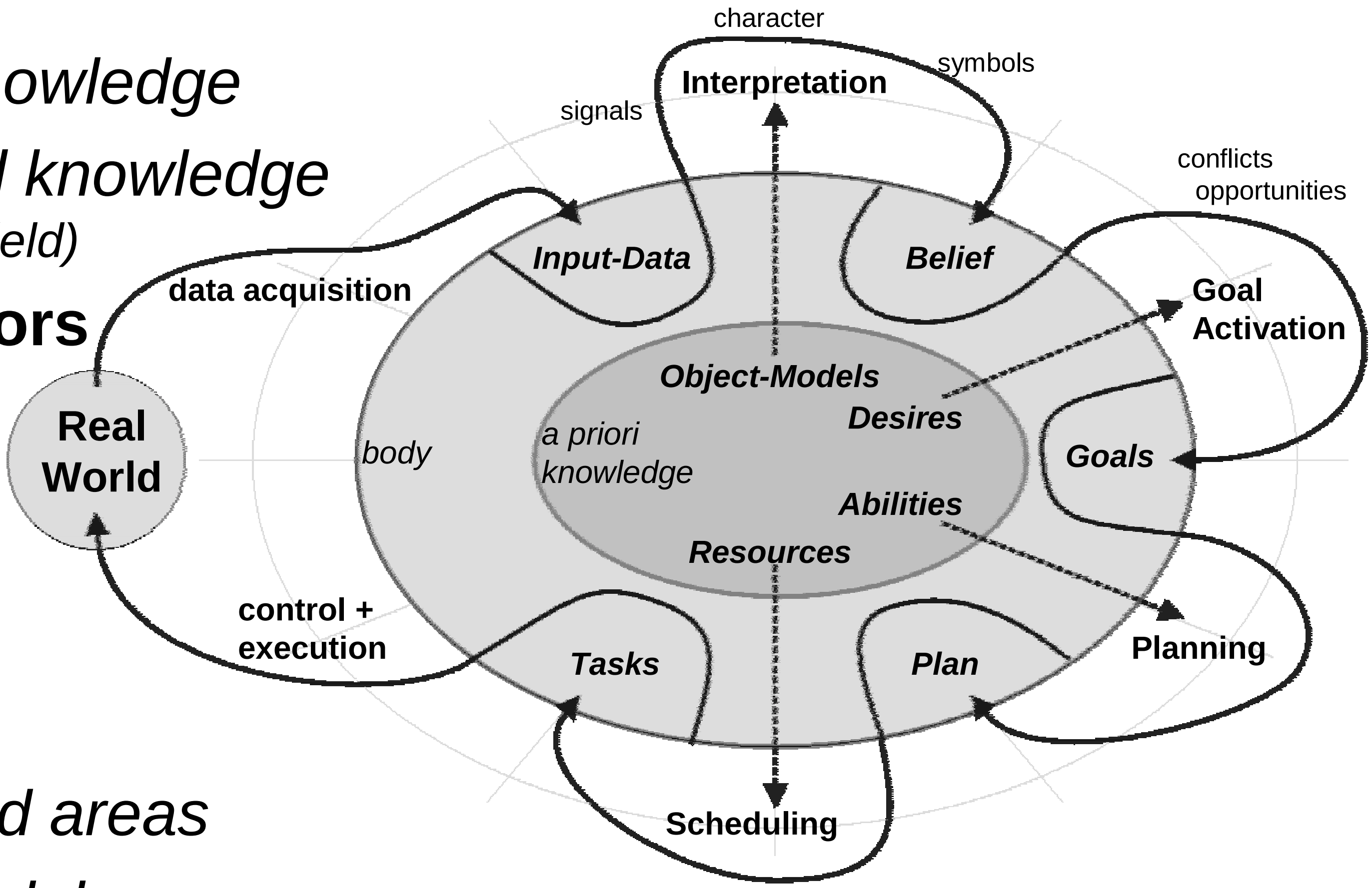
- **functional view**
  - ➥ *cognitive system*
  - ➥ *cooperative system*
  - ➥ *symbolic knowledge processing*
  - ➥ *simulating human behavior*
    (system’s behavior is understandable)

the Cognitive Process

- **architectural view**
  - ➥ *distributed system and knowledge*
  - ➥ *separate architecture from application*
  - ➥ *maintainability, extendibility*
  - ➥ *uniform representation*
  - ➥ *knowledge processor*

Substructure for all Cognitive Processes

- **body** (data)**:**
  - ↳ *a-priori knowledge*
  - ↳ *generated knowledge* *(=cognitive yield)*
- **transformators** (functions)**:**
  - ↳ *reading in whole body*
  - ↳ *writing in designated areas*
  - ↳ *use of models*



- **cognitive process consists of 4 transformators (+ I/O)**

Decomposition and OO approach

- **the Cognitive Process is the fix architecture**
  - ➩ *target systems are established solely by ‘communicating’ a priori knowledge into the body*
  - ➩ *this knowledge as the uniform structure of models*

- **object models from an image of the real world**
  - ➩ *templates have functions describing the behavior of each instance (including creation and deletion)*
  - ➩ *instances have data members describing the state*

- **aggregation**
  - ➩ *the combination of all micro behaviors of all objects within the body of the cognitive process form the macro behavior of the whole system.*

Analysis

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- **architectural view**
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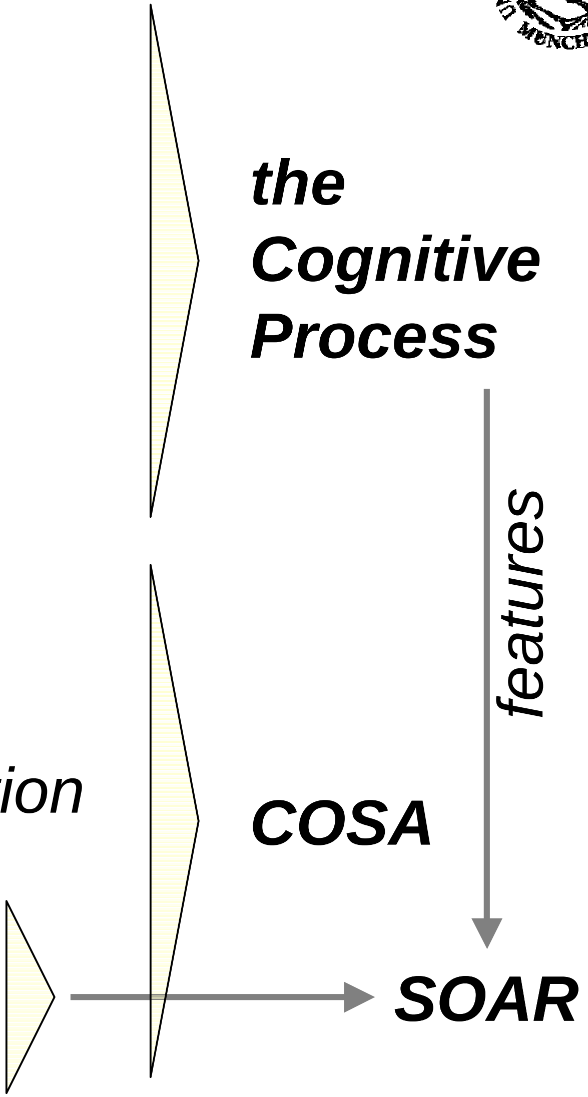

What is COSA?

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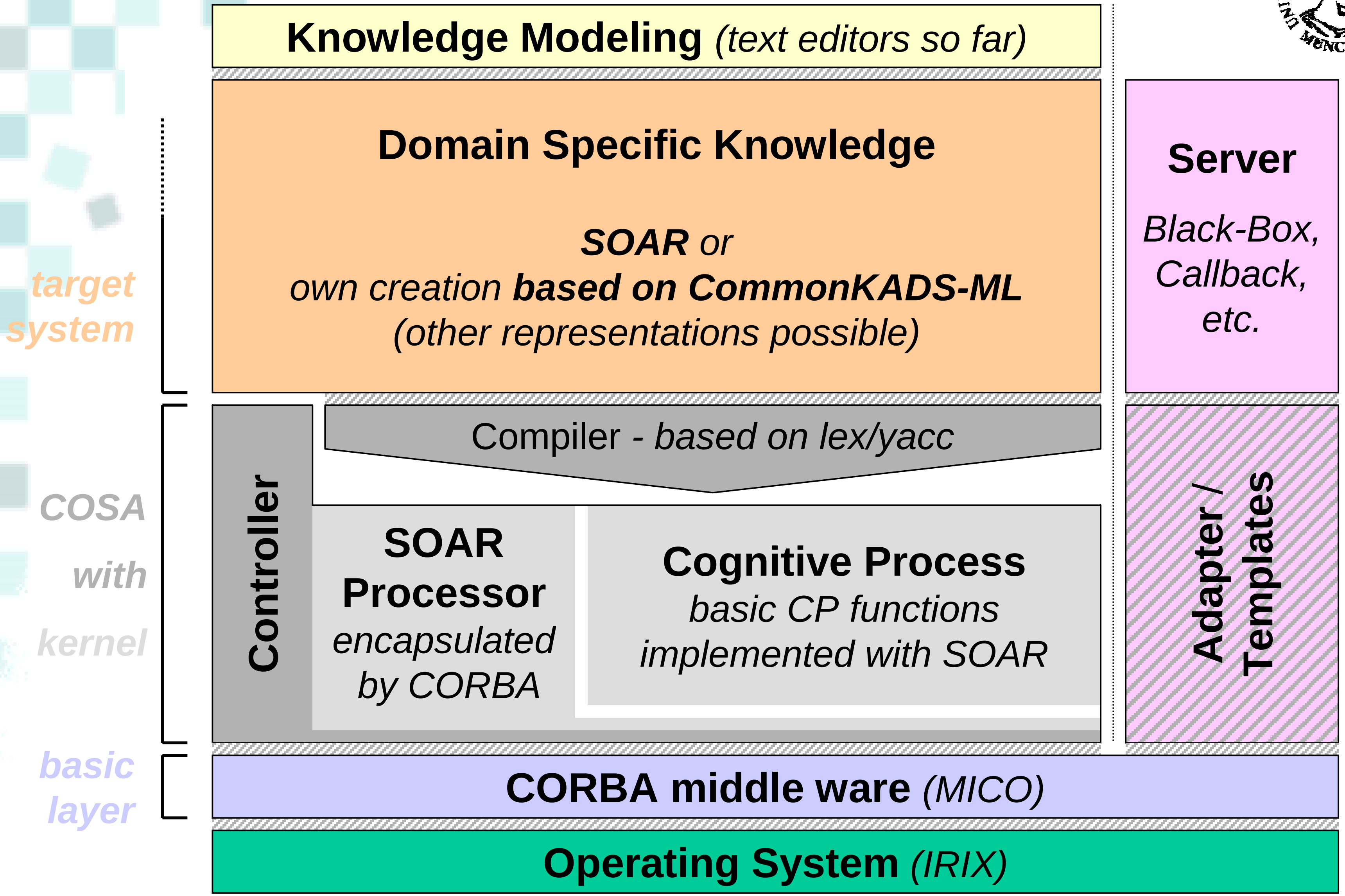
COSA

- **Kernel**
  - ↳ *Processor: SOAR*
    - » uniform data (WM)
    - » uniform algorithm / behavior (rules)
  - ↳ *Library: Cognitive Process*
    - » realizes the Cognitive Process
    - » object oriented abstraction in SOAR
    - » knows about components
- **CORBA encapsulation**
  - » distributed system / component handling (make use of kernel)
  - » knowledge abstraction (wrapping for distribution via CORBA)
  - » interfacing with other (external) systems (e.g. in the cockpit)
- **Language Front End**
  - ↳ *Compiler*
    - » input is knowledge, which is compiled to run on the kernel
    - » other knowledge descriptions (besides SOAR) are possible

COSA: block model architecture



Knowledge Modeling *(text editors so far)*

Domain Specific Knowledge

SOAR *or*
own creation ***based on CommonKADS-ML***
(other representations possible)

Server

Black-Box,
Callback,
etc.

target system

Compiler - *based on lex/yacc*

Controller

SOAR Processor
encapsulated by CORBA

Cognitive Process
basic CP functions implemented with SOAR

Adapter / Templates

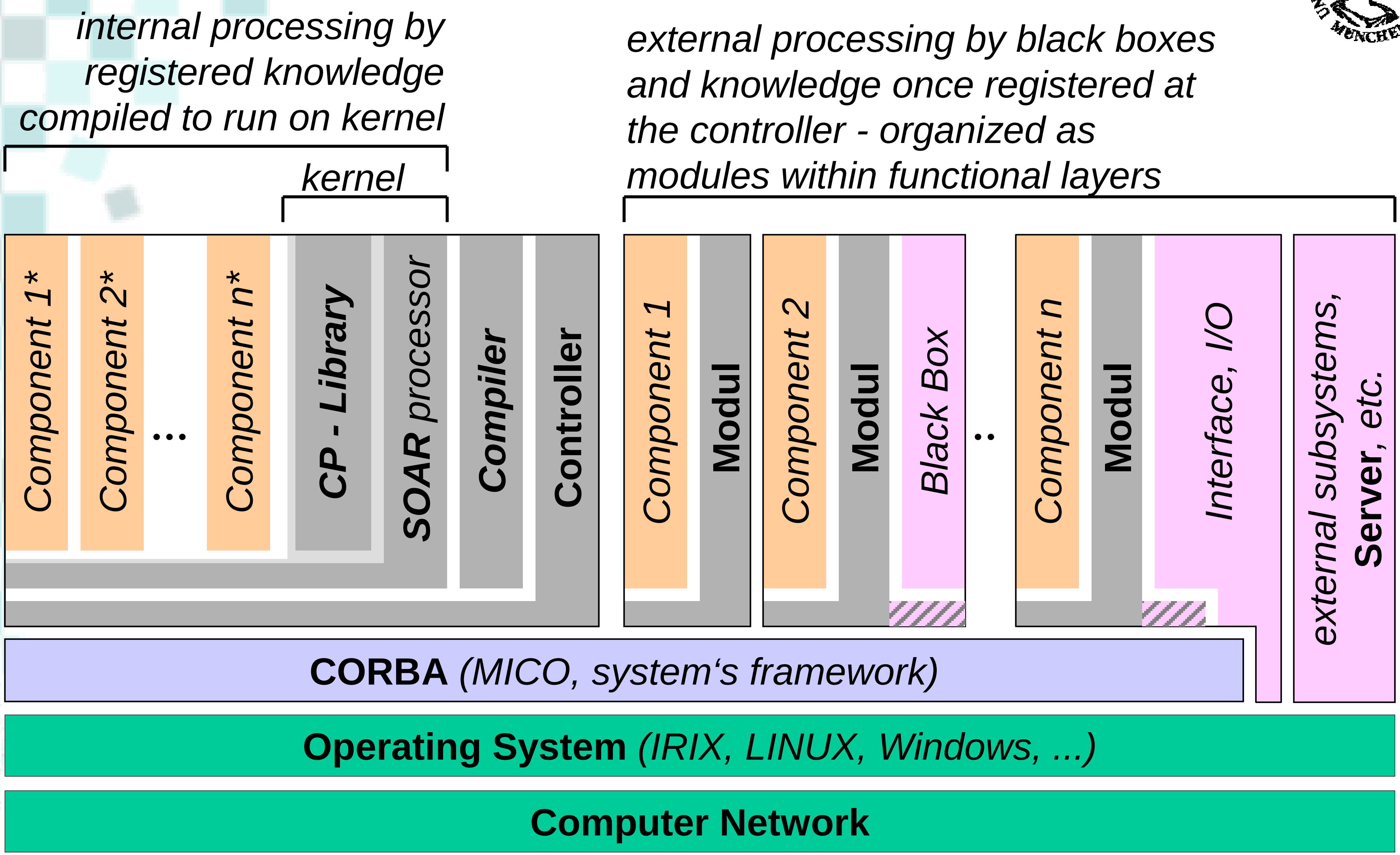
COSA with kernel

basic layer

CORBA middle ware *(MICO)*

Operating System *(IRIX)*

COSA: Layer Model of Architecture



internal processing by registered knowledge compiled to run on kernel
kernel
external processing by black boxes and knowledge once registered at the controller - organized as modules within functional layers
Component 1*
Component 2*
...
Component n*
CP - Library
SOAR processor
Compiler
Controller
Component 1
Modul
Component 2
Modul
Black Box
..
Component n
Modul
Interface, I/O
external subsystems, Server, etc.
CORBA (MICO, system‘s framework)
Operating System (IRIX, LINUX, Windows, ...)
Computer Network

What can COSA be used for?

- **goals**
  - ↳ *high level decisions / decision support*
  - ↳ *implement the Cognitive Process*
  - ↳ *complex symbolic processing*
  - ↳ *distributed system*
  - ↳ *separation of architecture and target system*
  - ↳ *flexible knowledge front end and reuse of knowledge*

- **not addressed** *(but can be done by extern. components)*
  - ↳ *high frequent control loops*
  - ↳ *number crunching*

How do we use SOAR ?

COSA - Usage of SOAR

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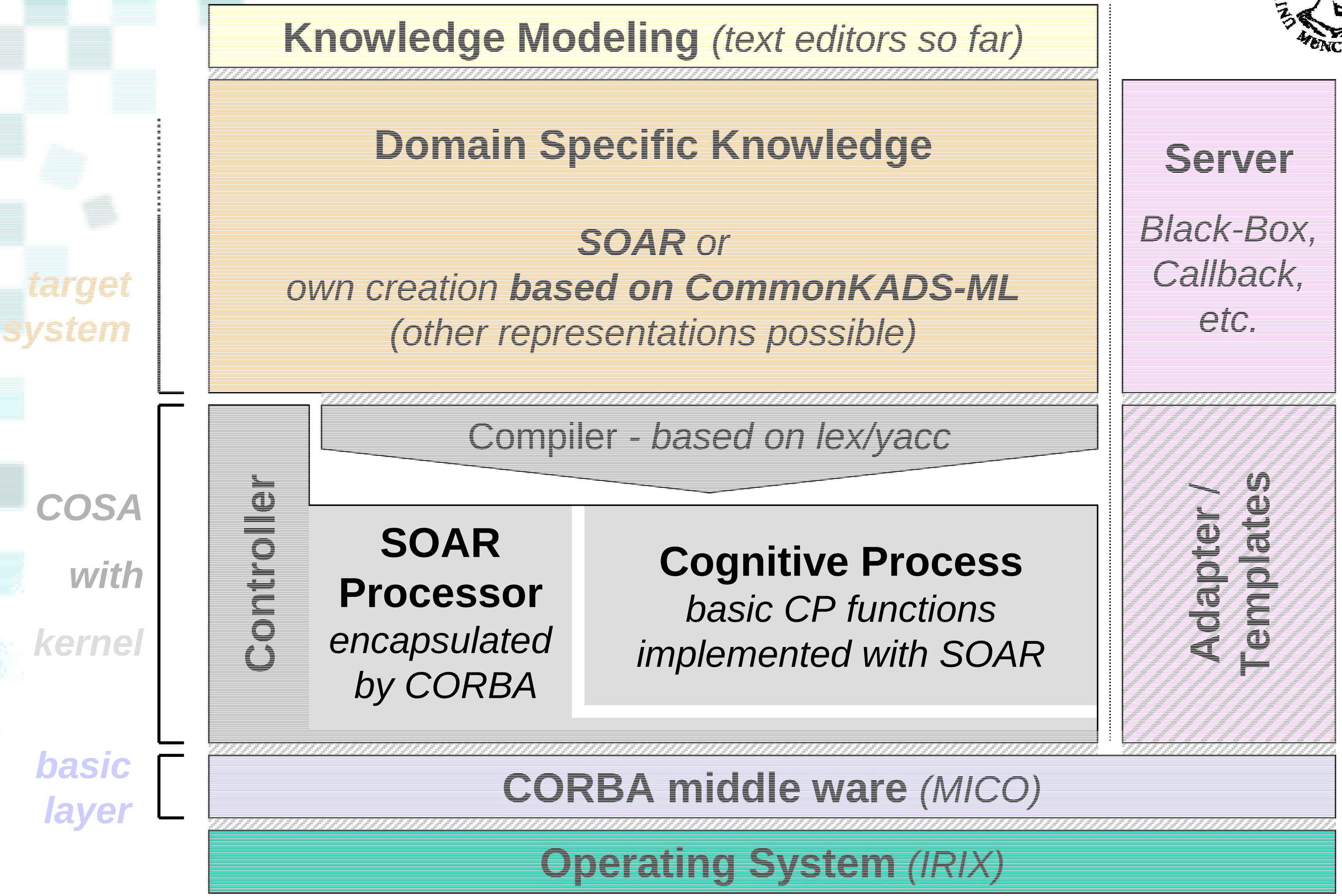
Locating SOAR with in COSA



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Operating System *(IRIX)*

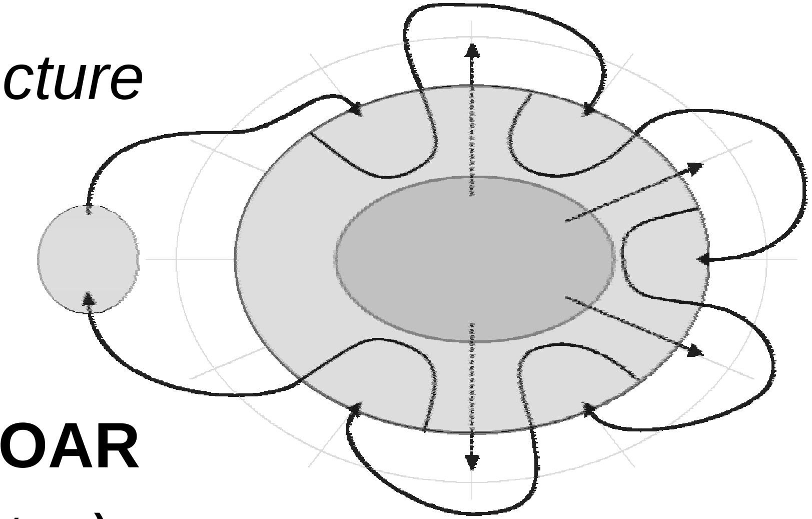
Usage of SOAR within COSA

- **Kernel is formed by SOAR**
  - ➪ *SOAR is the processor*
  - ➪ *SOAR library implementing the Cognitive Process (CP-Library)*

- **Why SOAR ?**
  - ➪ *Uniform representation of knowledge: WM*
  - ➪ *Uniform representation of behavioral parts: productions*
  - ➪ *features and research in many areas we need*
    - ➢ learning
    - ➢ cooperation with other agents
    - ➢ using several levels of knowledge
    - ➢ **…** *(much more)*

Features of the CP-Library

- **Cognitive Process is the top level SOAR state**
- **organization of WM**
  - ⇘ *special area used by architecture*
    - ➢ components, signals, ...
  - ⇘ *a-priori-knowledge*
  - ⇘ *cognitive yield*



- **object oriented view within SOAR**
  - ⇘ *classes (= models or templates)*
  - ⇘ *instances*
  - ⇘ *process of creation and deletion*
  - ⇘ *behavior or instances*
  - ⇘ *inheritance (data members (=attributes) only)*

CP-Library - The ‘global’ tree

- **‘`global`’ is an augmentation of each state**
  - *automatically linked to every state at creation time*
- **the ‘`global`’ tree within the WM includes**
  - *‘**`trigger`**’ - for internal synchronization (signals)*
    (unused so far, but tests are running)
  - *‘**`components`**’ - to organize registered components*
    - component dependencies
    - monitor state
      (activation, errors, ...)
    - operator selection within SOAR
  - *‘**body**’*
    - a-priori knowledge and cognitive yield

```
(S1 ^global G1)
  (G1 ^trigger T1 )
  (G1 ^components C1)
  (G1 ^body B1)
```

CP-Library - Components

```
(S1 ^global.components C1)
 (C1 ^comp C2 C3 C4 ... )

   (C4 ^name |name|)
   (C4 ^type [sys,cpt,model])
   (C4 ^uses <comp>* )
   (C4 ^connect t)

   (C4 ^depend <comp*>)
   (C4 ^active t)
   (C4 ^rang [int])
```

- **representation of**
  - *internal components*
    (system or transformators)
  - *external components*
    (parts of target system)
- **augmentations**
  - ‘**`name`**’, ‘**`type`**’
  - ‘**`used`**’ *components*
  - ‘**`connect`**’ - *true if all used components are found*
- **architecture generates**
  - ‘**`depend`**’ - *transitive hull of* ‘**`used`**’
  - ‘**`active`**’ - *true if connected and all depend are active*
  - ‘**`rang`**’ - *kind of comp. hierarchy for operator selection*

CP-Library - Body

- ‘**body**’ **area ...**
  - *is part of the* ‘`global`’ *structure*
  - *represents the data within the cognitive process*
    - a priori data = ‘`model`’
    - cognitive yield = ‘`instance`’

```
(S1 ^global.body B1)

 (B1 ^belief B4)
   (B4 ^model M1)
   (B4 ^instance I1)

 (B1 ^goal G4)
   (G4 ^model M1)
   (G4 ^instance I1)

 (B1 ^plan P4)
   (P4 ^model M1)
   (P4 ^instance I1)

 (B1 ^schedule S4)
   (S4 ^model M1)
   (S4 ^instance I1)
```

CP-Library - Models

- **models are part of components**
- **models consist of**
  - *a general description*

    This is the ‘class’ or the ‘template’ with all possible attributes, optional default values and information about inheritance.
  - *productions for creation*
  - *productions for the behavior of instances*

```
(S1 ^global.body.belief B9)
 (B9 ^model M1 M2 M3 ... )
 (B9 ^instance I1 I2 I3 ... )

  (M1 ^name aircraft)
  (M1 ^attrib A1 A2 ... )
    (A1 ^name callsign)
    (A2 ^name alt ^default 0)
    ...

  (I1 ^name own-vehicle)
  (I1 ^model M1)
  (I1 ^callsign |D-ADAM| )
  (I1 ^alt 0)
  ...
```

- **architecture provides operators for instantiation and attribute consistency in case of inheritance**

CP-Library - Overview

- **COSA**
  - ➩ *is a system architecture which uses SOAR*

- **SOAR is the kernel of COSA**
  - ➩ *SOAR processor*
    - ➢ all research of SOAR community (re-) usable
  - ➩ *SOAR library implementing the Cognitive Process*
    - ➢organization and object oriented view by models

What about the CORBA encapsulation ?

COSA - Wrapping SOAR with CORBA

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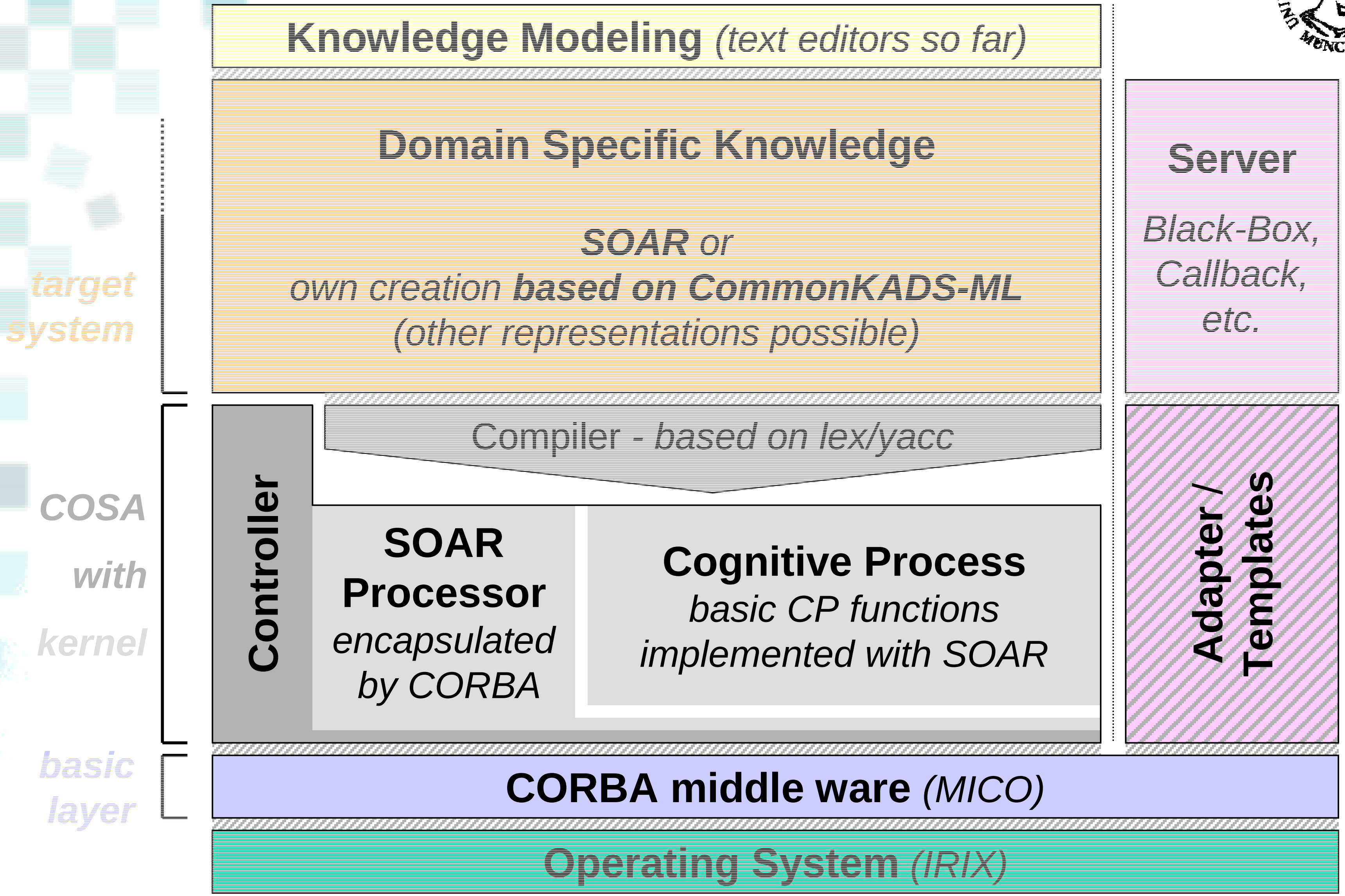
Wrapping with CORBA - COSA architecture



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target system

COSA with kernel

basic layer

Wrapping with CORBA - Why wrapping SOAR?

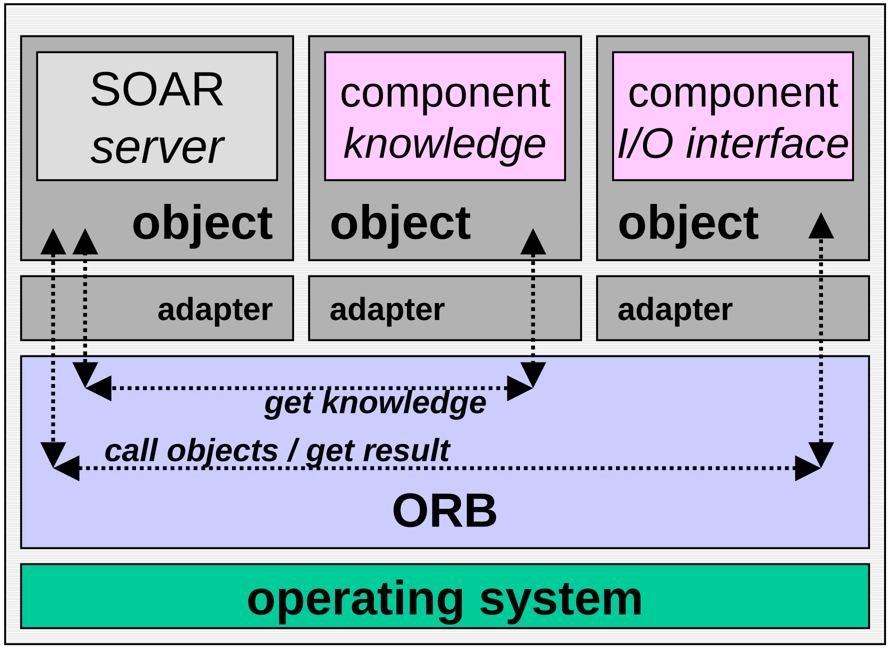
- **SOAR has ...**
  - ➯ *central situation representation (working memory)*
  - ➯ *efficient implementation of access (rules)*
  - ➯ *uniform representation of data (WMEs)*
  - ➯ *uniform representation of algorithms (productions)*

- **SOAR lacks ...**
  - ➯ *ability to be used in distributed environments*
  - ➯ *interface to handle components*

➯ ***CORBA is good at these deficiencies***

Wrapping with CORBA - What is CORBA?

- **Common Object Request Broker Architecture**
  - ⇘ *industrial standard for distributed systems*
  - ⇘ *middle ware to connect software components*
  - ⇘ *client-server system*
  - ⇘ *OO replacement for RPC*



- **features**
  - ⇘ *independent of programming language*
  - ⇘ *independent of operating system*
  - ⇘ *independent of hardware (even network)*
  - ⇘ *easy to use*

Wrapping with CORBA

- **SOAR elements which need to be wrapped**

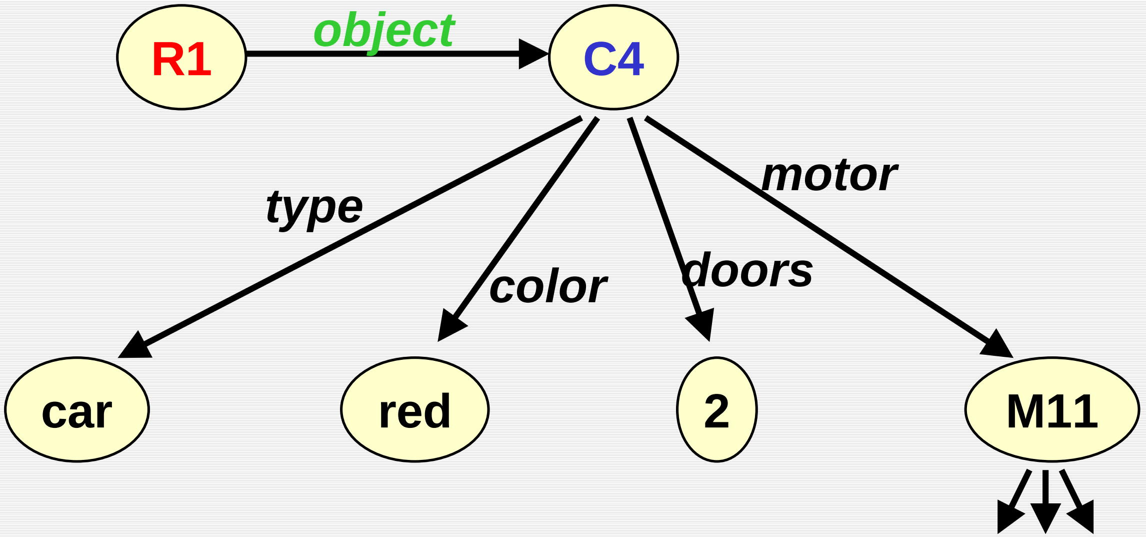
  - *knowledge*
    - build a suitable abstraction of the working memory
    - have interface to let CORBA objects communicate
  - *I/O functions, RHS functions*
    - call functions via the network
    - transfer and receive small portions of knowledge
  - *callbacks*
    - no uniform interfacing to SOAR

Wrapping Knowledge - Concept

- **knowledge abstraction**
  ↳ *similar to conceptual graph (others are possible, e.g. frames)*

```
( R1 ^object C4 )


( C4 ^type  car )
( C4 ^color red )
( C4 ^doors 2 )
( C4 ^motor M11 )
   ( M11 ... )
```



- **interfaces possible**
  ❶ *copy and reintegrate areas of the WM: easy to use*
  ❷ *have 'pointer' access: highest flexibility*

Wrapping Knowledge - Solved Problems

☑ **mapping SOAR types to CORBA**

- ➪ *straight forward mapping of values (integer, string, ...)*
- ➪ *special mapping for nodes which are not a value*

☑ **depth of copying WMEs**

- ➪ *given by structure of models within COSA*

☑ **reintegration with links to other symbols in the WM**

- ➪ *used special mapping and internal SOAR functions*

☒ **‘pointer’ access**

- ➪ *not yet available, but experimented with it*
- ➪ *consequences might not be intended !*
  (location of knowledge)

Wrapping Functions - Concept

Example: RHS function

❶ **COSA kernel**

↳ *convert parameters into knowledge graphs*

↳ *send knowledge to appropriate component*

❷ **component**

↳ *receive parameters*

↳ *calculate return result*

❸ **COSA kernel**

↳ *receive and unpack result*

↳ *reintegrate into WM*

Note:
*RHS-function ‘***`sqt`***’ must be registered within the controller*

```
sp {test*production
 (state <s> ^operator <o>)
 (<o> ^name calc-sqt
 (<o> ^value <v>)
-->
 (<o> ^result (call sqt <v>))
}
```

Wrapping Functions - integration into SOAR

- **registering dispatcher as SOAR callbacks**
  - » function: **link** between SOAR callbacks and object oriented world
  - » input: gets **target object’s name** as parameters along with call
  - » action: **dispatches the call** to that object
- **using dispatcher for ...**

➯ *special RHS functions*

- » need to use RHS function ‘**`call`**’
- » first parameter defines the target CORBA object
- » following parameters define the parameters to the call

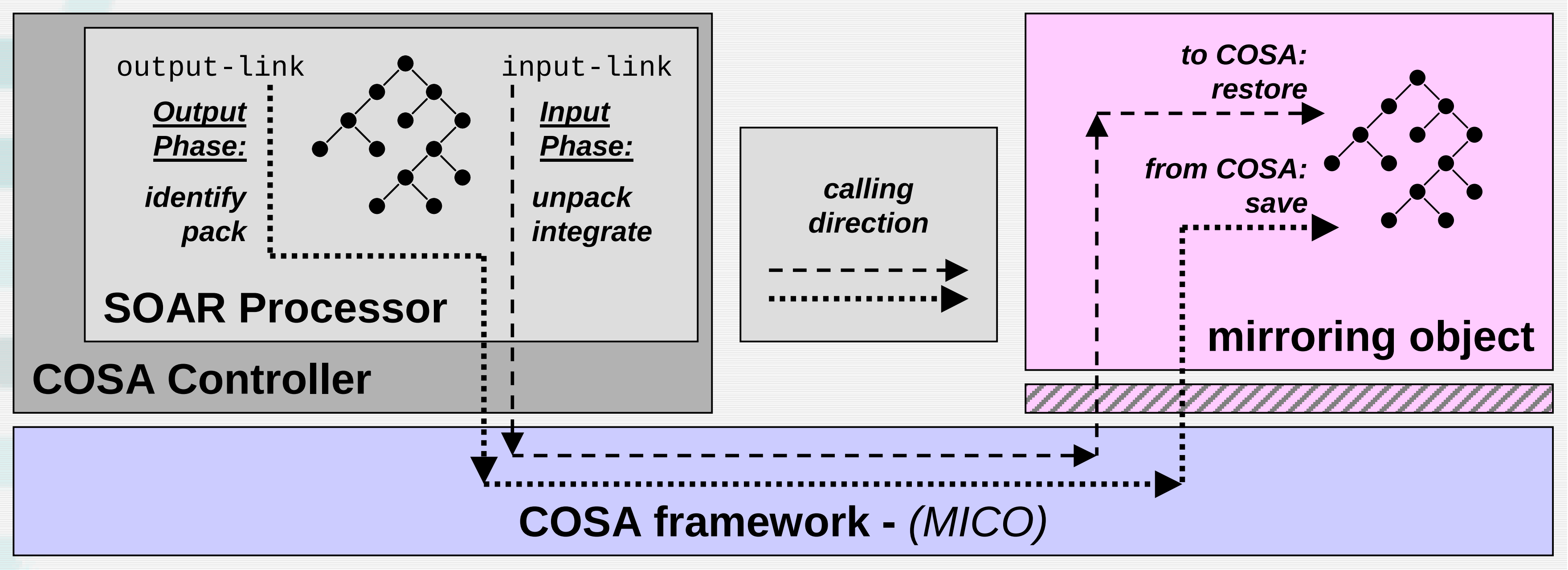
➯ *special I/O-callbacks executed during I/O phase*

- » target CORBA object is derived from structure of **`io-link`**
- » parts of the **`output-link`** are transmitted while output phase
- » incoming knowledge (input phase) is stored at the **`input-link`**

➯ *callbacks (not implemented so far - not needed so far)*

Wrapping with CORBA - Benchmark

- **setup of bench:**
  - ⇘ *COSA server and 'mirroring' object; test I/O phase*



- **duration of one SOAR cycle** *(on a dual 250 MHz Octane, IRIX6.5)*
  - ⇘ *38ms / 60ms (for 113 nodes and 108 edges, local / via network)*
  - ⇘ *72ms / 100ms (for 226 nodes and 216 edges, local / via network)*

Wrapping with CORBA - Implementation

- **using MICO**
  - ⇨ *CORBA is a standard, MICO is a free implementation (see http://www.mico.org)*
- **using the Standard Template Library STL**
  - ⇨ *standard C++ library*
  - ⇨ *easy to use classes to handle knowledge graphs*
- **using the new C API of SOAR**
  - ⇨ *extended in some areas*
- **documented with “doxygen”**
  - ⇨ *free tool (see http://www.stack.nl/~dimitri/doxygen)*
  - ⇨ *generates documentation from special C++ comments*
  - ⇨ *“doxygen” is used for the C API as well*

What is the “language front end” ?

COSA - language front end

COSA

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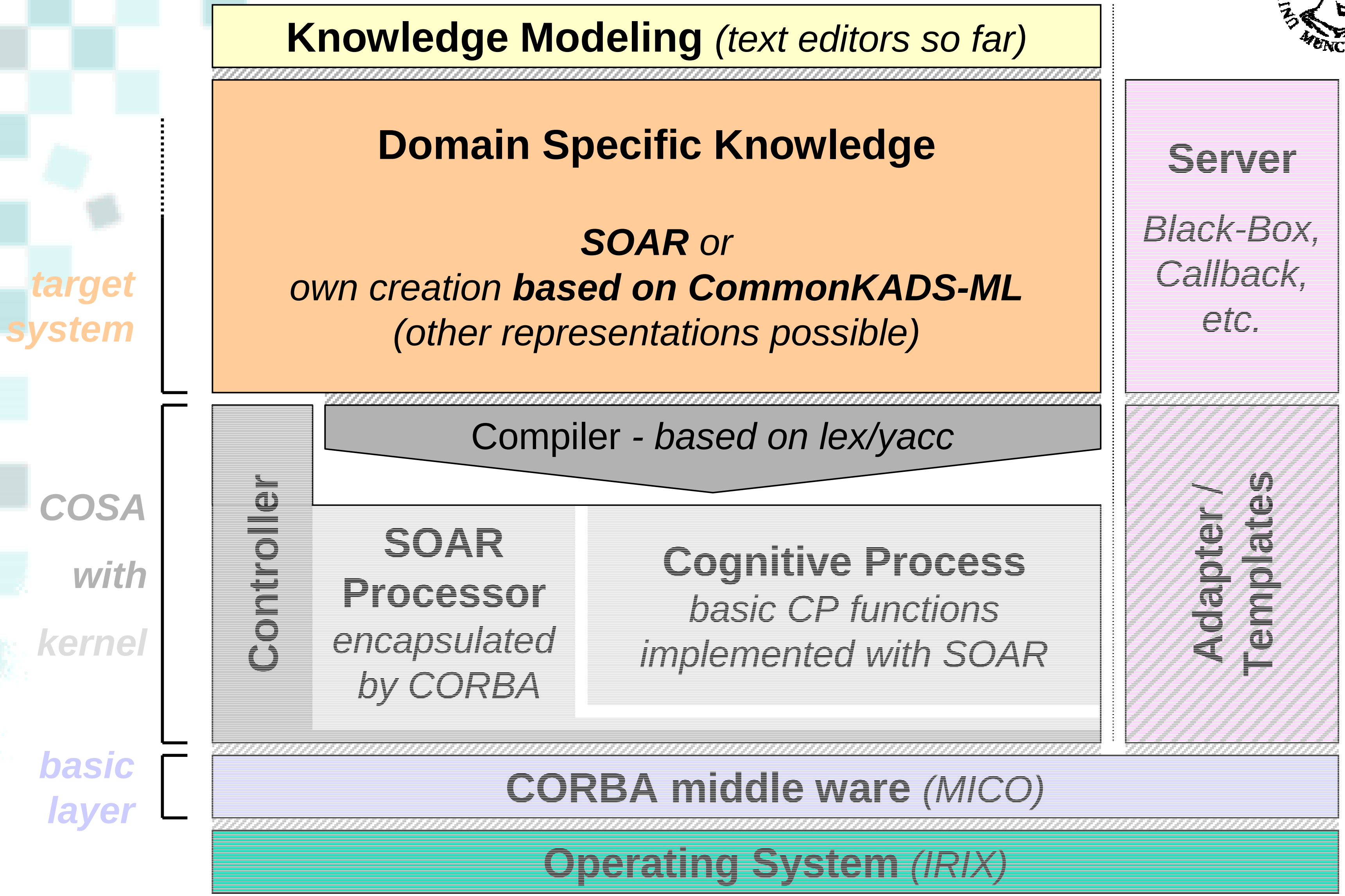
Language front end - components of COSA



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target
system
COSA
with
kernel
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layer

Language front end - features

- **language front end**
  - ↳ *compiled to run on the COSA kernel*
  - ↳ *will save the user from the need of learning SOAR*
- **main problem**
  - ↳ *(not only) mapping to SOAR*
  - ↳ *mapping on to the kernel of COSA:*
    SOAR and the Cognitive Process library
  - ↳ *languages are basing on own model, not CP*
- **first promising tries are using CommonKADS-ML**
- **others are planned**
  - ↳ *more object oriented languages (similar to C++ ?)*

Summary and Conclusion

What have we done ?

- **COSA - cognitive system architecture**
  - ⇨ *new approach towards cognitive systems*
- **wrapped SOAR with CORBA**
  - ⇨ *knowledge processor of COSA*
  - ⇨ *distributed system*
  - ⇨ *knowledge mapping similar to conceptual graph*
- **cognitive process**
  - ⇨ *implementation on top of SOAR*
  - ⇨ *introduced an object oriented view (models) to SOAR*
- **languages / knowledge front end**
  - ⇨ *first abstractions towards other representations*

Actual State

- **state of implementation**
  - ⇘ *SOAR wrapper in use*
    - » speed improvements planned if necessary
  - ⇘ *Prototype using COSA is running (COSY^{flight})*
    - » simple implementation in some areas of the cognitive process
    - » improvements and further development

- **future**
  - ⇘ *perfecting COSA and the SOAR kernel in it*
  - ⇘ *improve existing and add new knowledge front ends*
  - ⇘ *<u>next milestone</u>: build a more complex system (UAV)*

Benefit for others

- **use experience**
  - ➯ *limited; indirect by using COSA*
- **extend COSA to test other theories or languages**
  - ➯ *implementation of any block from the architecture can be changed*
- **use COSA as architecture - communicate knowledge**
  - ➯ *need to wait until it is ready to be used (2002)*
- **use wrapping of SOAR only**
  - ➯ *some minor work to do*
  - ➯ *no pure SOAR encapsulation*

Contact Information

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- **web**
  - ➱ *http://www.unibw-muenchen.de/campus/LRT/LRT13*

- **e-mail**
  - ➱ *Henrik.Putzer@UniBw-Muenchen.DE*

References

- **CORBA (standard of the Object Management Group)**
  - ↳*http://www.omg.org*
  - ↳*http://www.corba.org*
- **MICO (free CORMA implementation)**
  - ↳*http://www.mico.org*
- **DOXYGEN (free documentation tool)**
  - ↳*http://www.stack.nl/~dimitri/doxygen*