

Case Studies in Model-based Systems for Ecological and Environmental Applications

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Thanks to Ulrich Heller

Optimism - „We will preserve local flora and fauna“



- „In this area the Forest Department of the Pichavaram Mangroves has started management activities in 1995 in order to preserve the local flora and fauna.“

Meanwhile, Upstream ...

Dams in Cauvery River

Reduction of Sediments
in the River

Less Deposition in
River Delta

Trough-shaped Basin

Stagnant Water

Increased Salinity

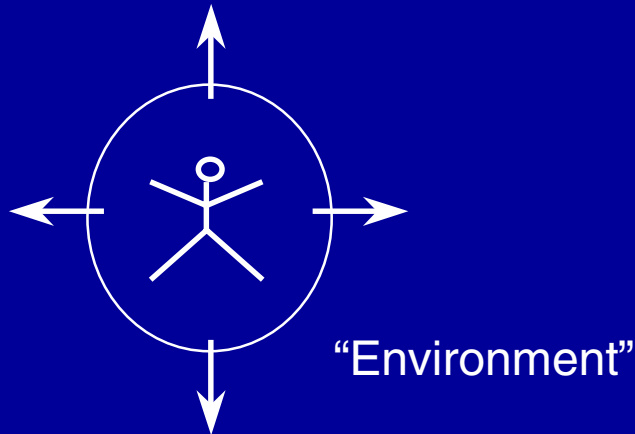
Degradation of Mangroves

Reduced Shelter Against Cyclones

The World - Simply Our “Environment”!

“Environmental Protection”

- Limit direct damage
- Preserve continued exploitation

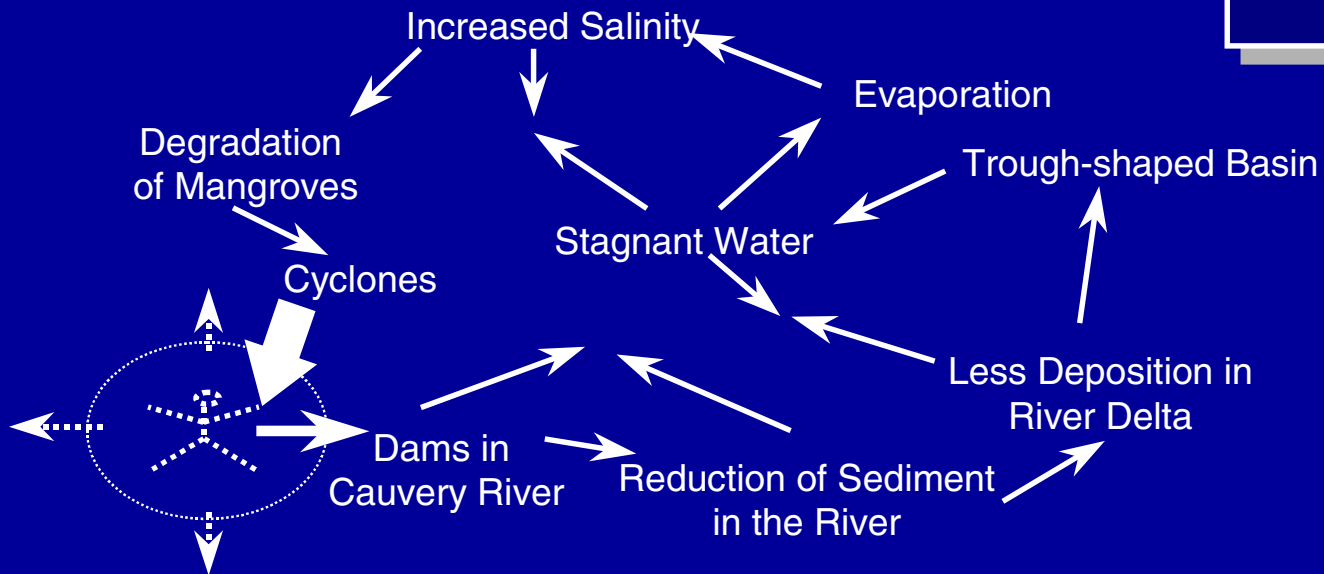


- Question “Do you believe, Earth is approaching an ecological catastrophe?”
- Answer: “There are certain hints we have to notice. But human skills for invention can solve the problems, if politicians pave the way.”

The World, Including Us

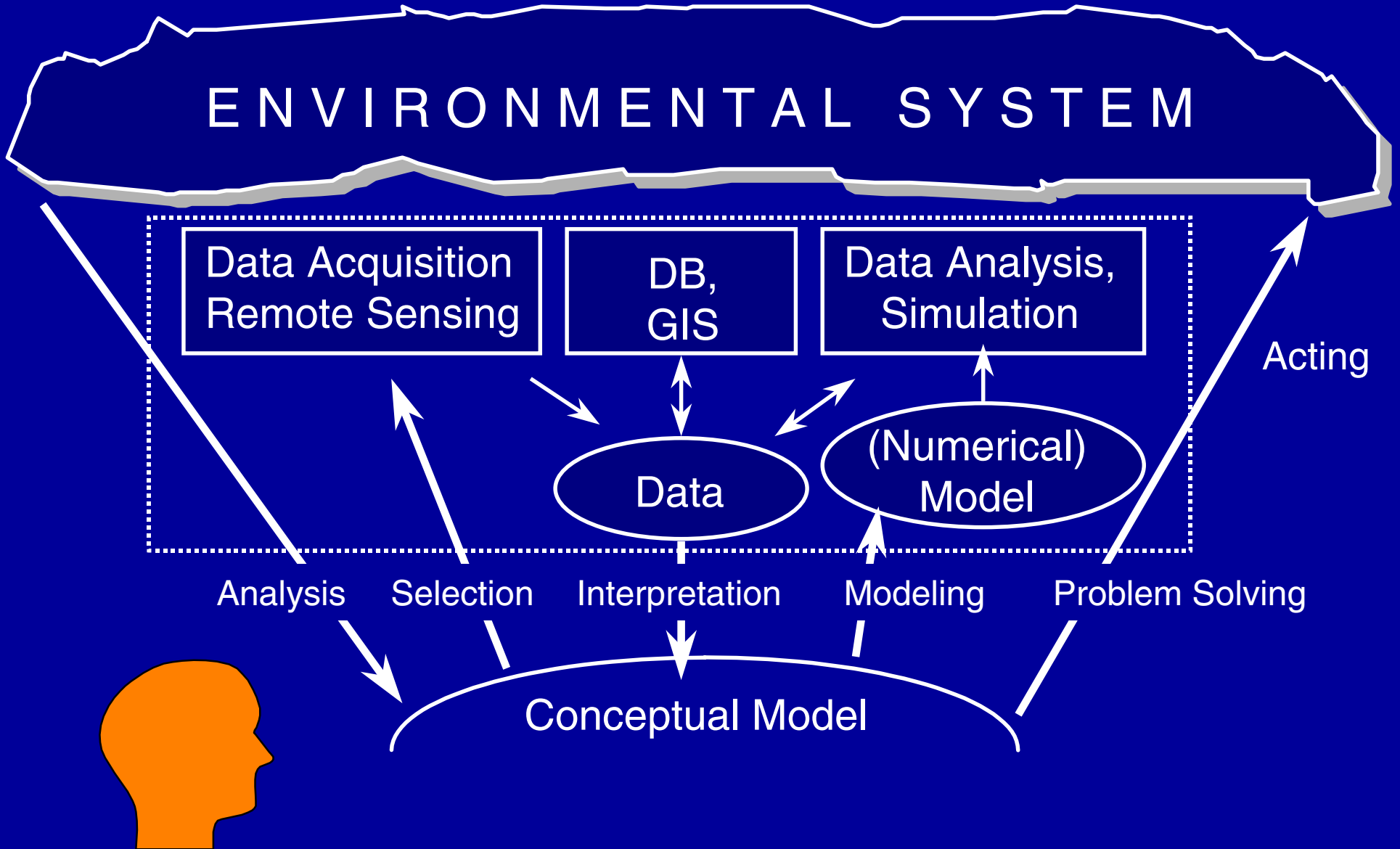
Understand!

- The complex interactions of natural phenomena and systems
- Human activities as additional influences in this network of interaction

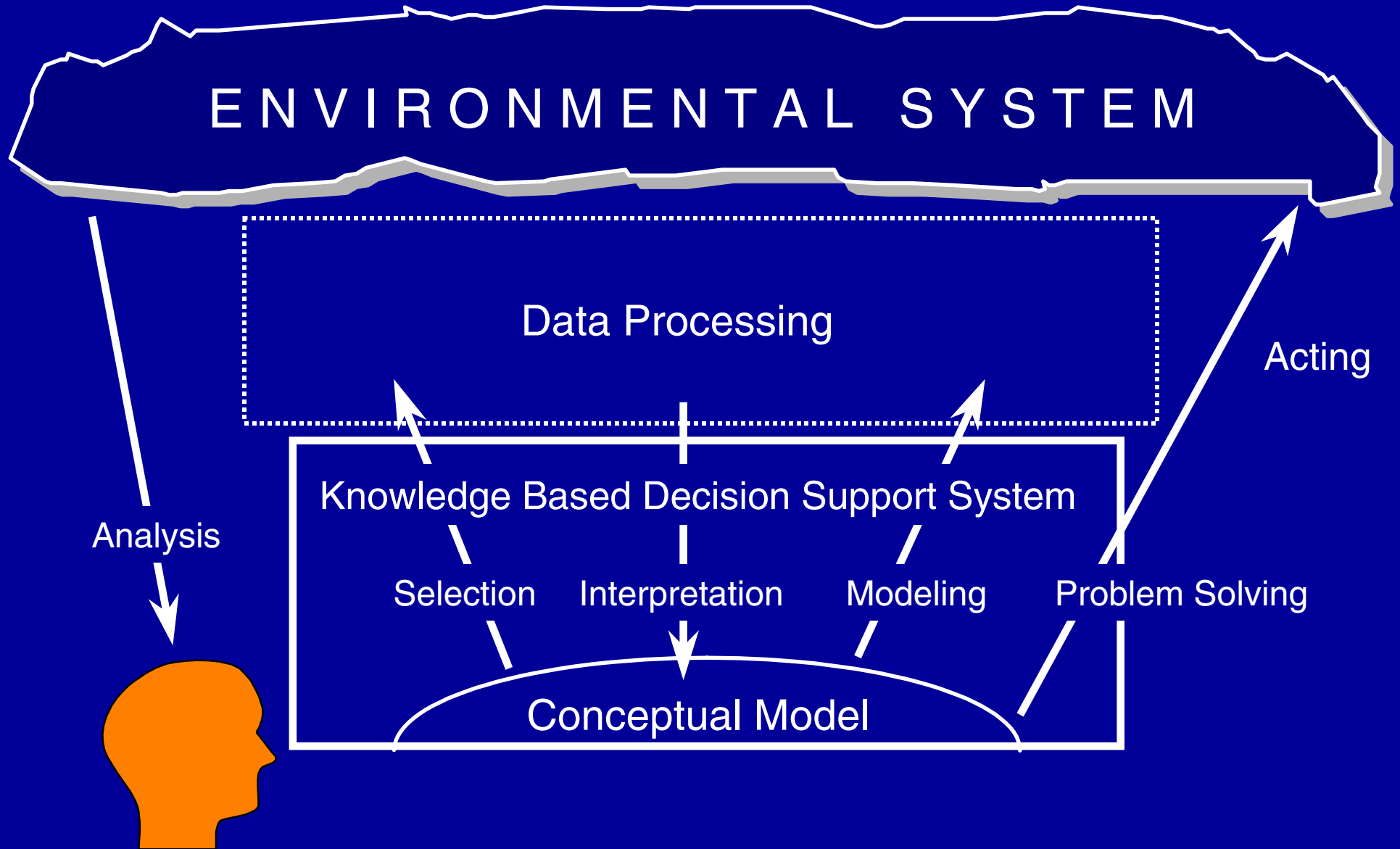


- Develop
 - Check
 - Revise
 - Improve
- Models !**

The Role of Information Technology



The Challenge for Knowledge Representation and Reasoning

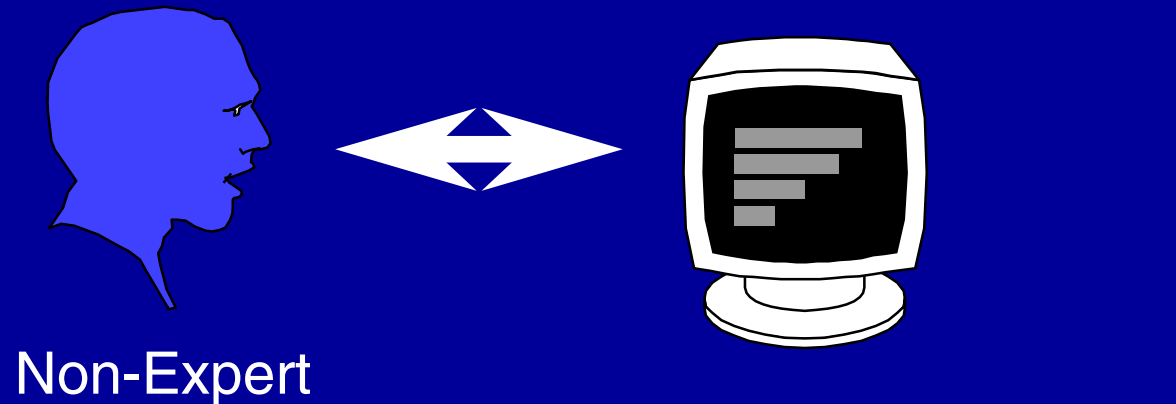


Mangrove Project - Requirements (1)

Supporting Local Decision Makers

(Forest dept., local self-administration, women's organizations)

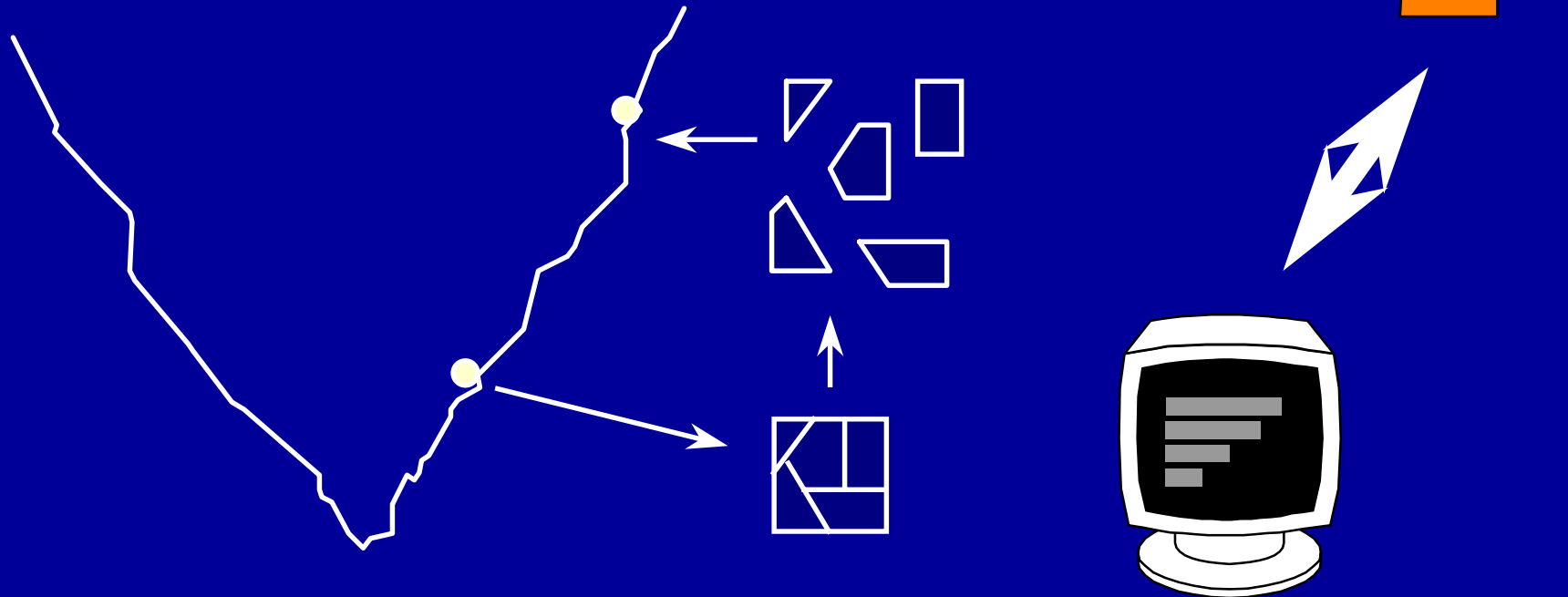
- Understanding, explanations
- Analysis, interpretation of observations
- Proposal and assessment of actions



Mangrove Project - Requirements (2)

Supporting Researchers

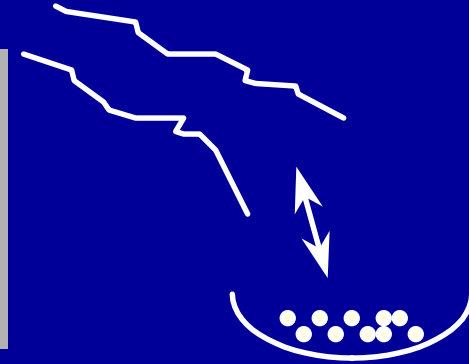
- Developing models
- Transfer of results
- Teaching



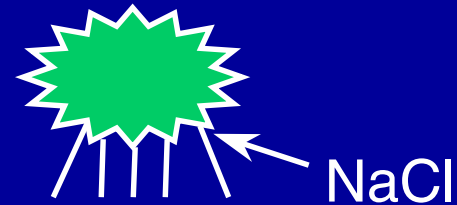
Mangrove Project - Requirements (3)

Domain Characteristics

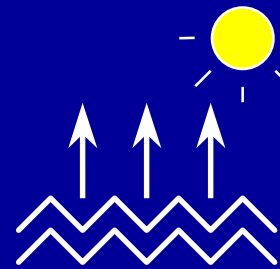
- Partial, qualitative knowledge
- Partial, qualitative information



Deposit of
Sediment



Effects of Salinity
on Mangroves

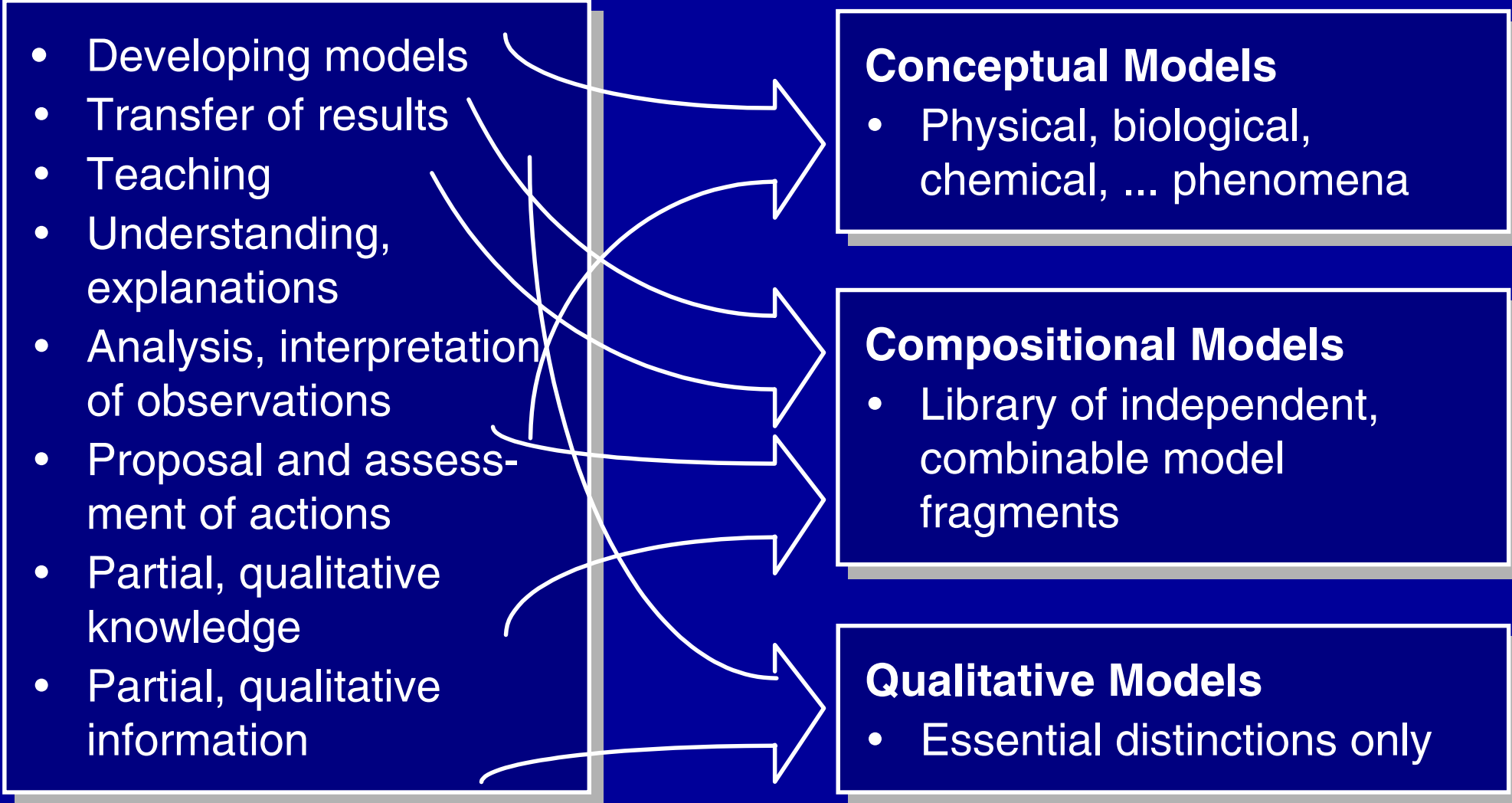


Evaporation
Rate



Amount of
Degradation

Requirements on Modeling

- Developing models
 - Transfer of results
 - Teaching
 - Understanding, explanations
 - Analysis, interpretation of observations
 - Proposal and assessment of actions
 - Partial, qualitative knowledge
 - Partial, qualitative information
- 

Conceptual Models

- Physical, biological, chemical, ... phenomena

Compositional Models

- Library of independent, combinable model fragments

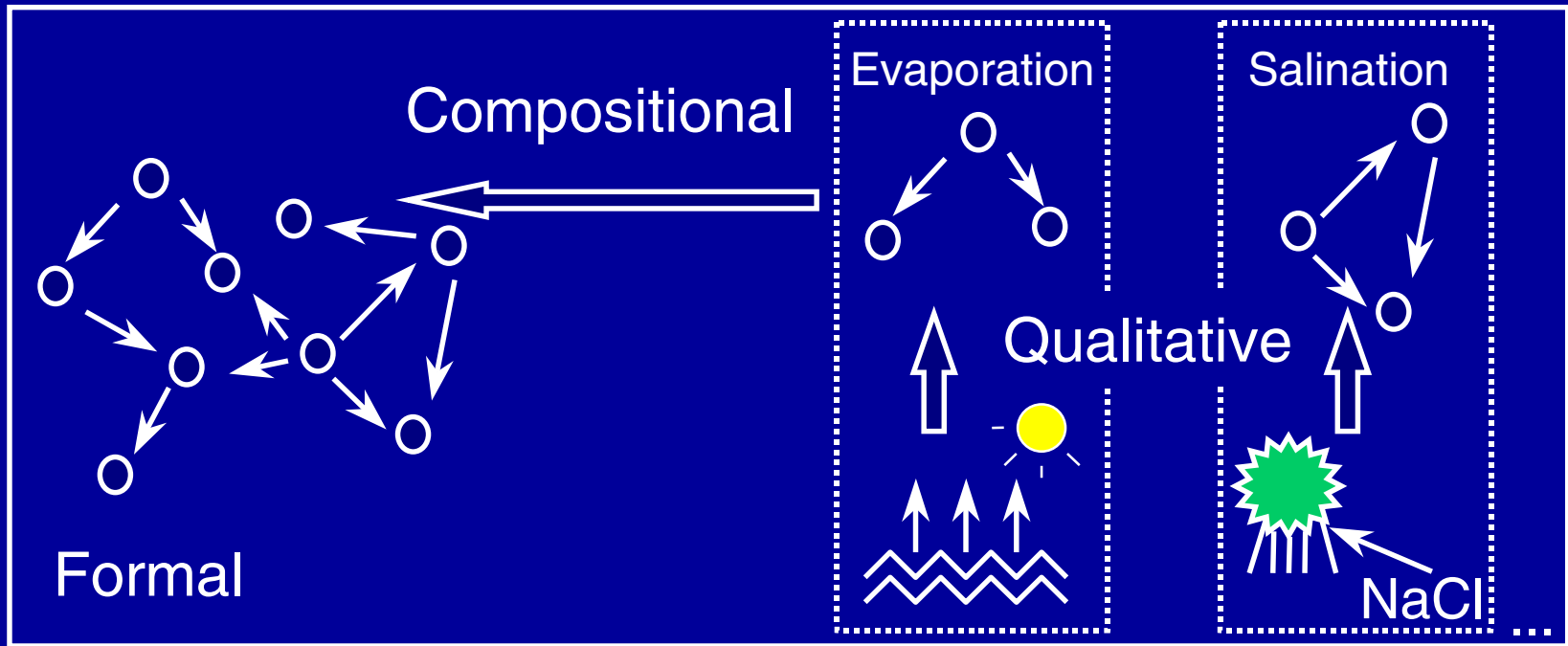
Qualitative Models

- Essential distinctions only

Modeling Support

ENVIRONMENTAL SYSTEM

Analysis



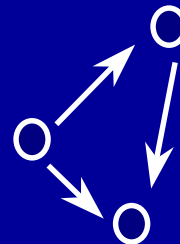
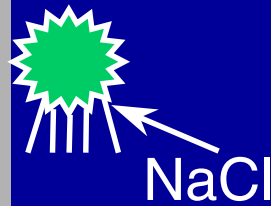
NaCl

Conceptual

Process-Oriented Modeling

Process: Model Fragment

- Condition
 - Structure (objects, object relations)
 - Quantities
- Behavior
 - Constraints (relation)
 - Partial influences



The Lomba Reservoir (Porto Alegre)



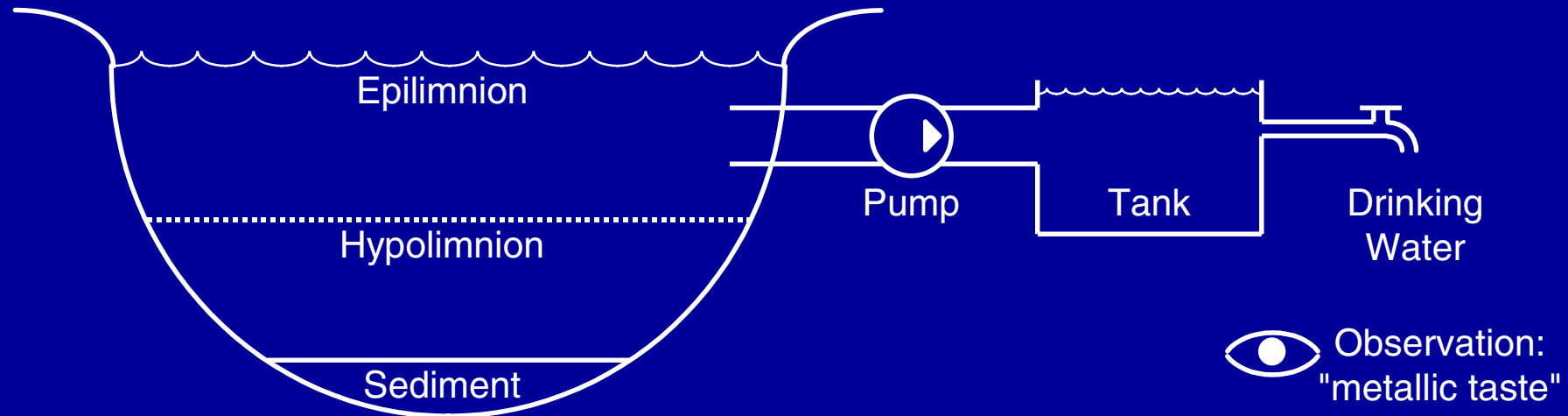
Algal Bloom



An Example from the Water Treatment Domain

The Problem

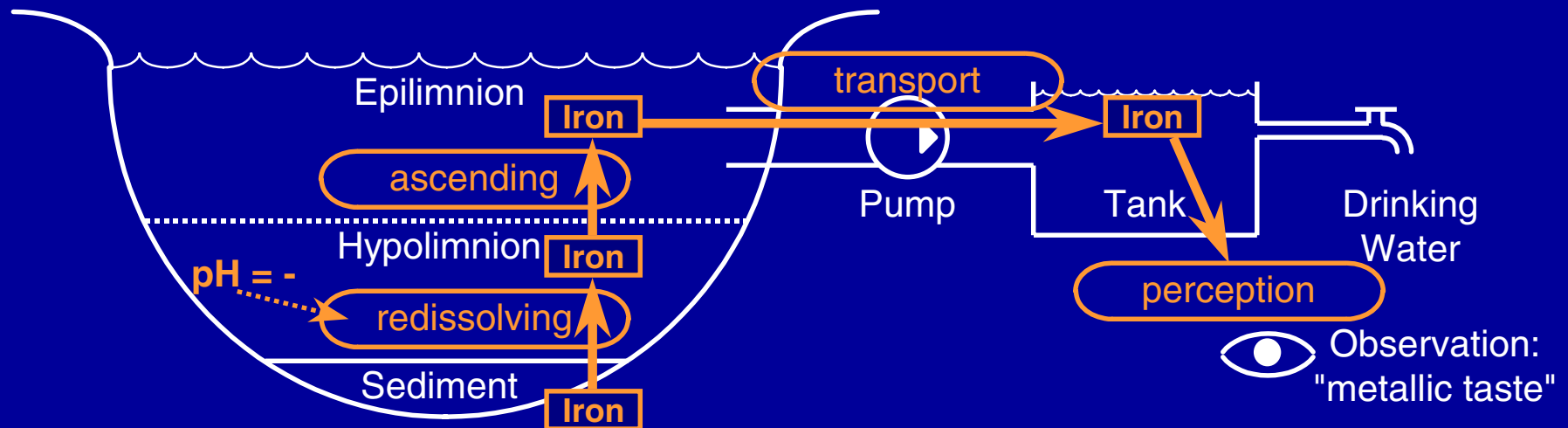
- High iron concentrations in drinking water produce bad taste (and odour)
- A potential source is the "re-dissolving" of iron from the sediment under acidic conditions



An Example from the Water Treatment Domain (continued)

Processes Occurring

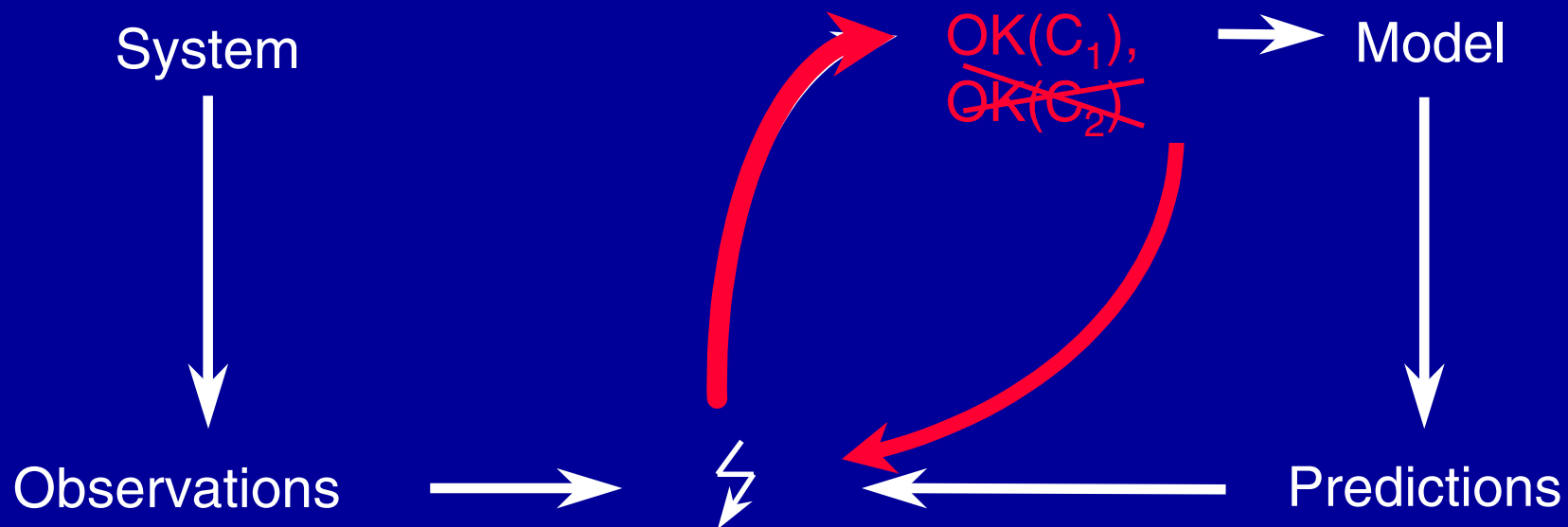
- The "metallic taste" is the human perception of iron in the water
- This has been transported (by pumping or ascending in the pond)
- Ultimately, it has been dissolved from the sediment
 - and for this to happen, acidic conditions are a precondition



Key Ideas: Generic Diagnosis Algorithm

Diagnosis:

- Find an assignment of a mode (Ok, Fault₁, ...) to each component C_i such that
- $SD \cup OBS \cup \{mode_i(C_i) \mid C_i \in COMPS\} \not\models \perp$



$SD \cup OBS \cup \{\text{mode}_i(C_i) \mid C_i \in \text{COMPS}\} \dots ?$

Processes are not faulty:

They are present/active or not, we have to look at the preconditions.

→ **No mode assumptions**

We don't blame an **existing** (behavior) constituent:

There are **additional** entities or unusual exogeneous conditions.

→ **No components (COMPS)**

A different strategy for model revision is needed

There are no “failures of nature”:

The phenomena are always in accordance with the laws of physics.

The conflict is with our intentions / goals!

→ **Explicit specification of GOALS needed**

Towards a New Theory of Model-based Diagnosis

More general

- Cover process-oriented models
- Account for unexpected interactions and objects
- Distinguish between different tasks
(more flexible)

→ **Beyond components**

More specific

- Specify vocabulary for ontology, structure and behavior
 - Formalization in logic
- **What's in SD?**

Include the standard component-oriented approach as a special case

Distinguish Different Tasks

What's going on? (situation assessment)

$$SD_0 \cup OBS \vdash \perp \longrightarrow SD_1 \cup OBS \not\vdash \perp$$

What's going wrong? (diagnosis)

$$SD_1 \cup GOALS \vdash \perp \longrightarrow SD_2 \cup GOALS \not\vdash \perp$$

What can be done? (therapy planning)

$$SD_1 \cup GOALS \vdash \perp \longrightarrow SD_1 \cup ACTIONS \cup GOALS \not\vdash \perp$$

What's in SD? - Survey

SD

- **DOMAIN THEORY**
 - **ONTOLOGY**
 - **STRUCTURE** (object types and object relation types)
 - **BEHAVIOR**
(quantity associations,
behavior constituent types with instantiation/activity rules)
 - **BASIC LAWS**
- **SYSTEM STRUCTURE**
(objects, object relations)
- **QUANTITY SPECIFICATIONS**
(variable and parameter values)

$$SD = SD_{rev} \cup SD_{fix}$$

Behavior Constituent Descriptions

Behavior constituent types:

- Process descriptions / component behavior models

Instantiation rules:

- (Structural) instantiation conditions: IC_i

$$IC_i \Rightarrow \exists Obj_j \wedge \text{beh-const}_j$$

Activity rules:

- (State dependent) activity conditions: AC_i

$$\text{beh-const}_i \wedge AC_i \Rightarrow \text{active}_i = T$$

Behavior description:

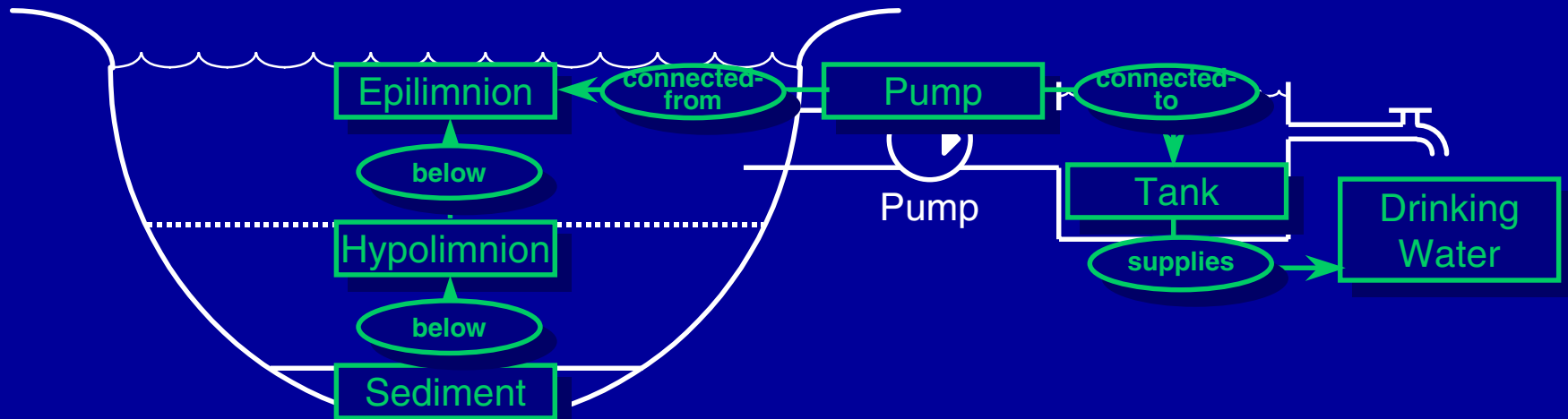
- Constraints and influences

$$\text{active}_i = T \Rightarrow \text{beh-constraints}_i \wedge \text{influences}_i$$

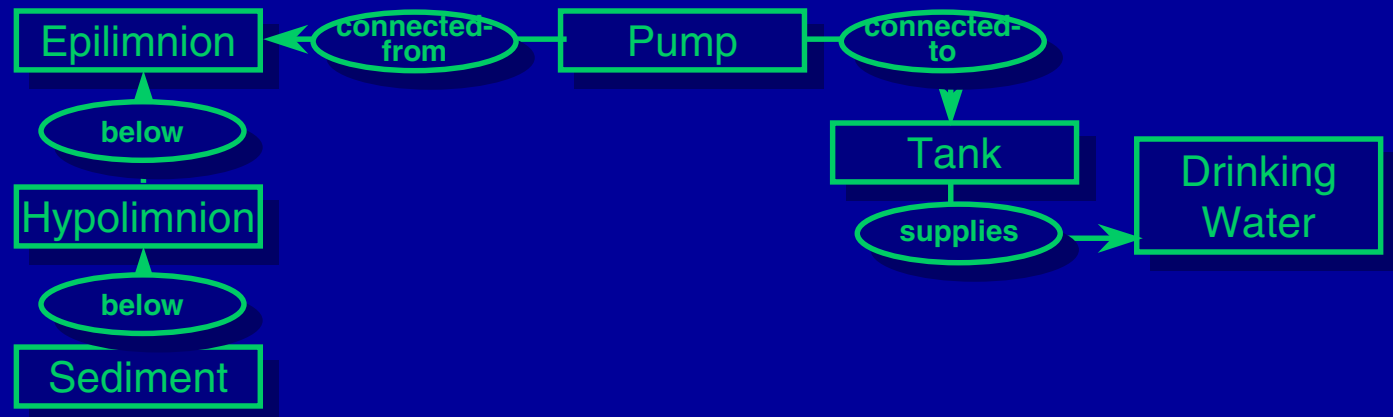
An Example from the Water Treatment Domain - Modelling

Modeling the scenario

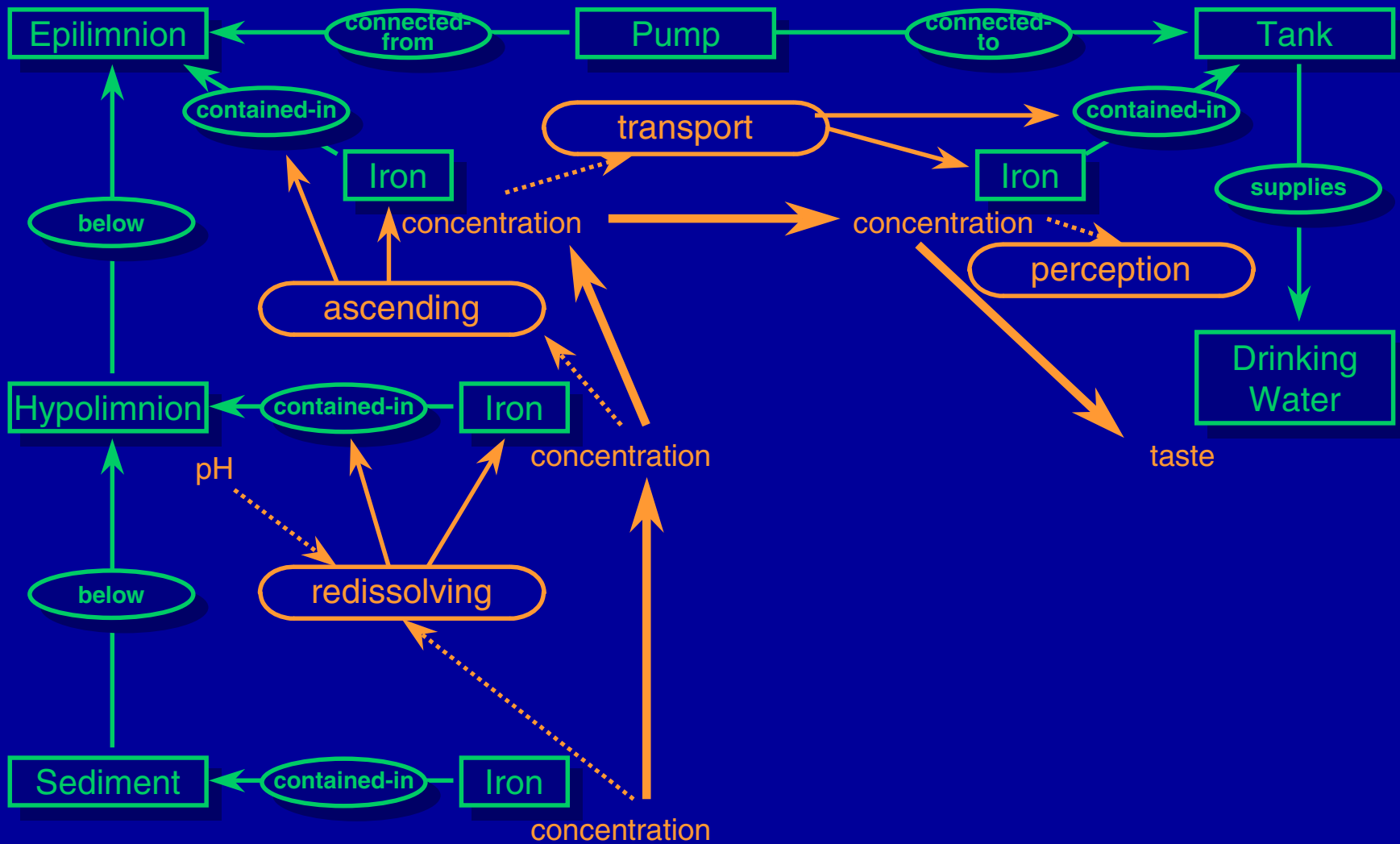
- Objects for spatial locators, components, substances, ...
- A set of relations complement the object structure



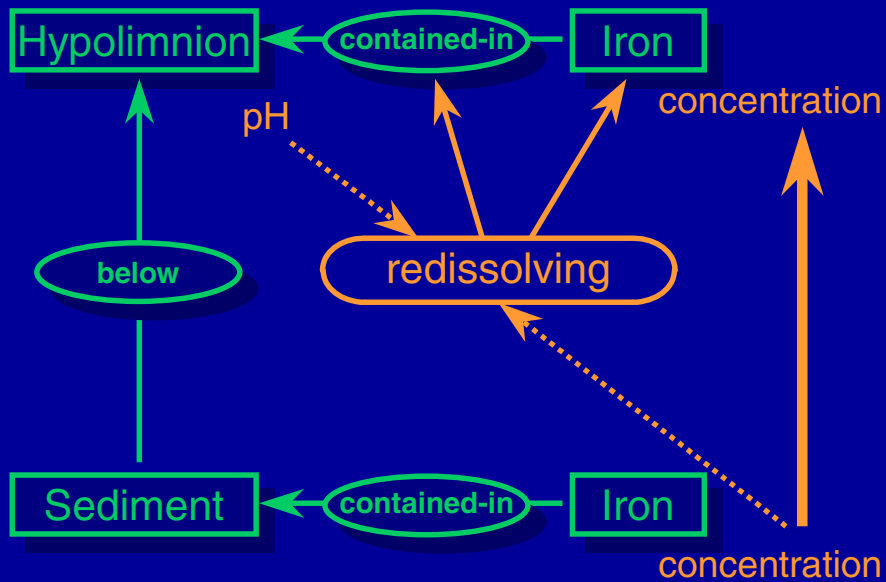
An Example from the Water Treatment Domain - Modelling



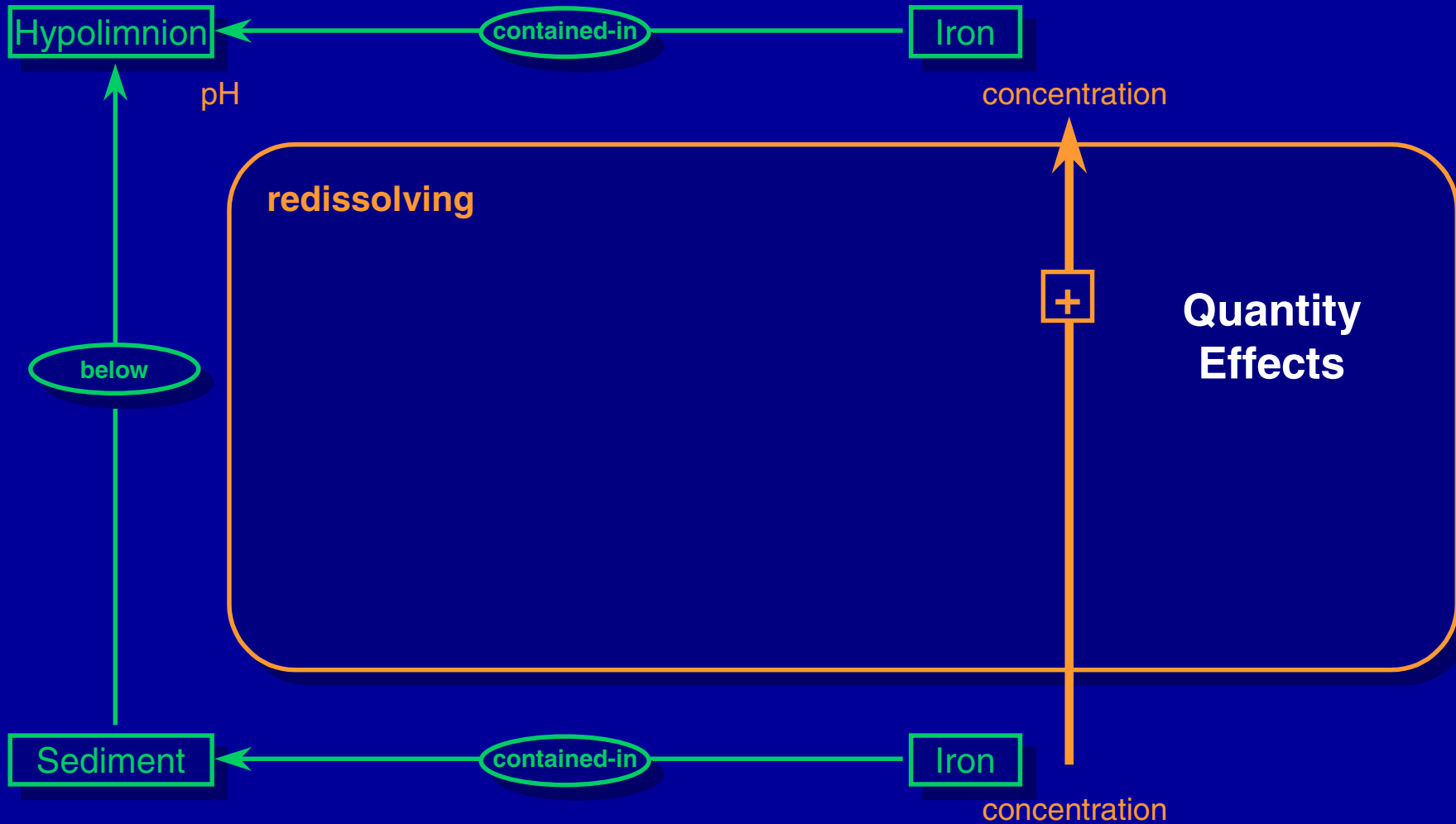
Example - Processes: Conditions and Effects



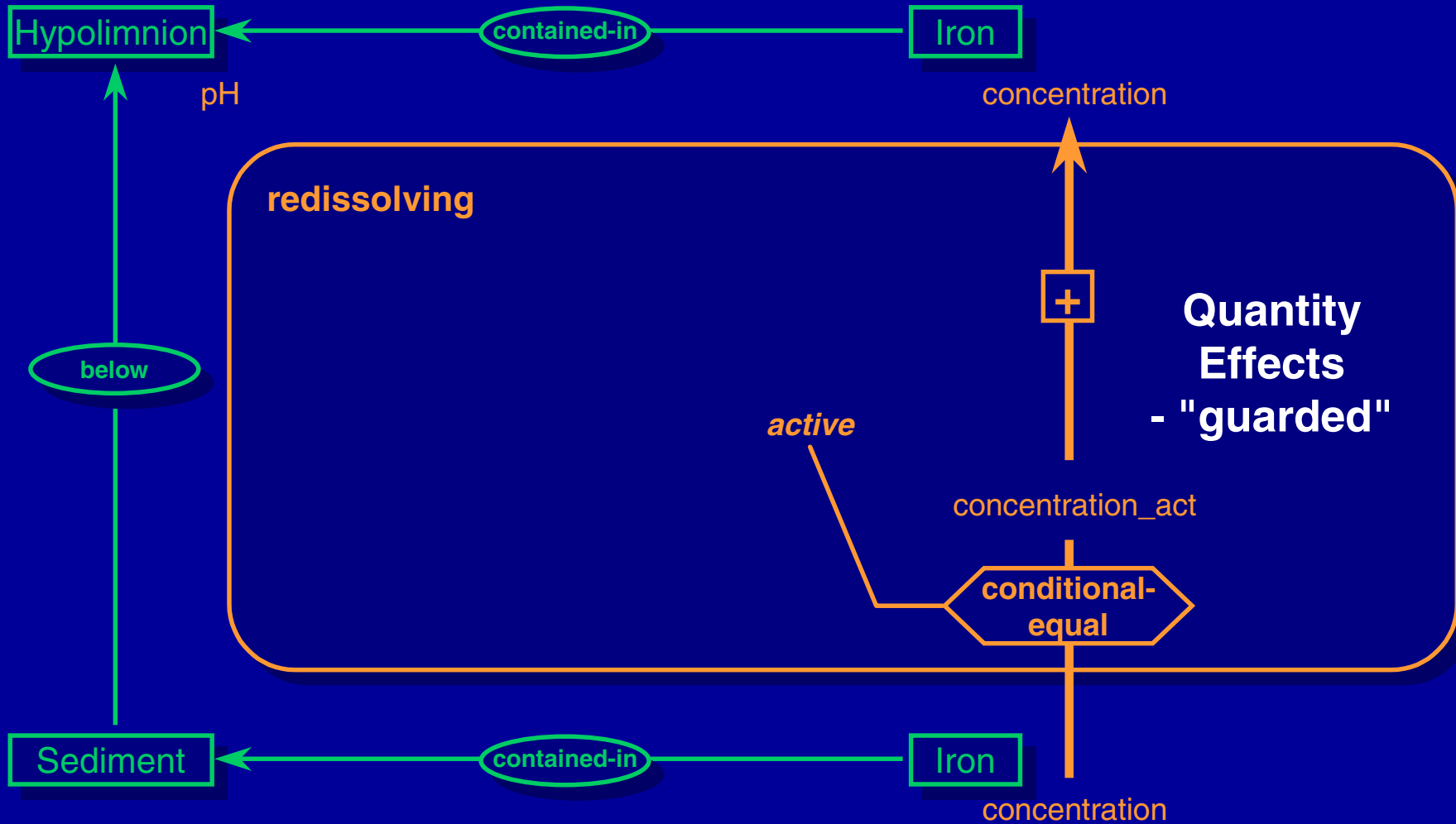
Example - Details of Conditions and Effects



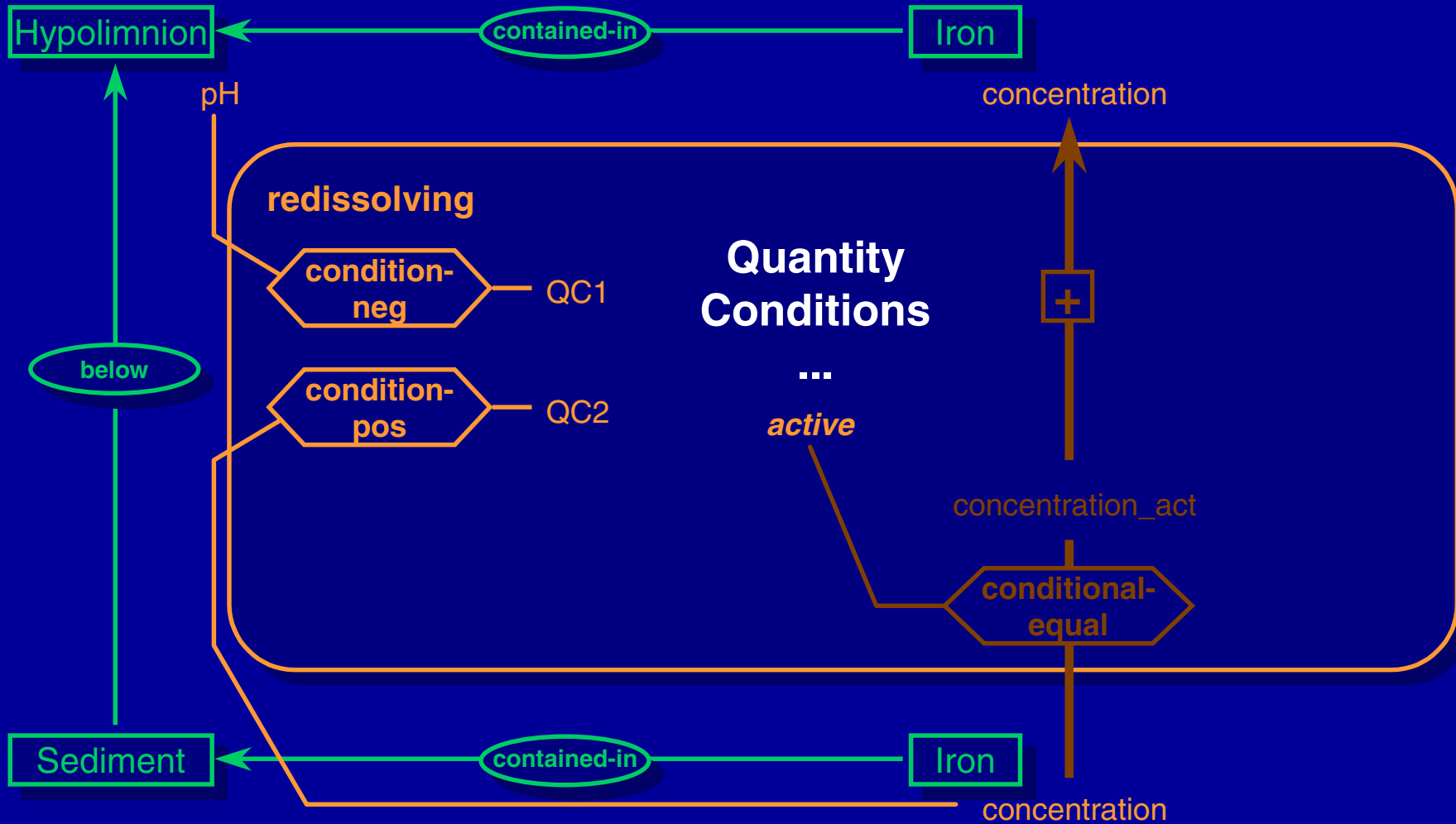
Example - Details of Conditions and Effects



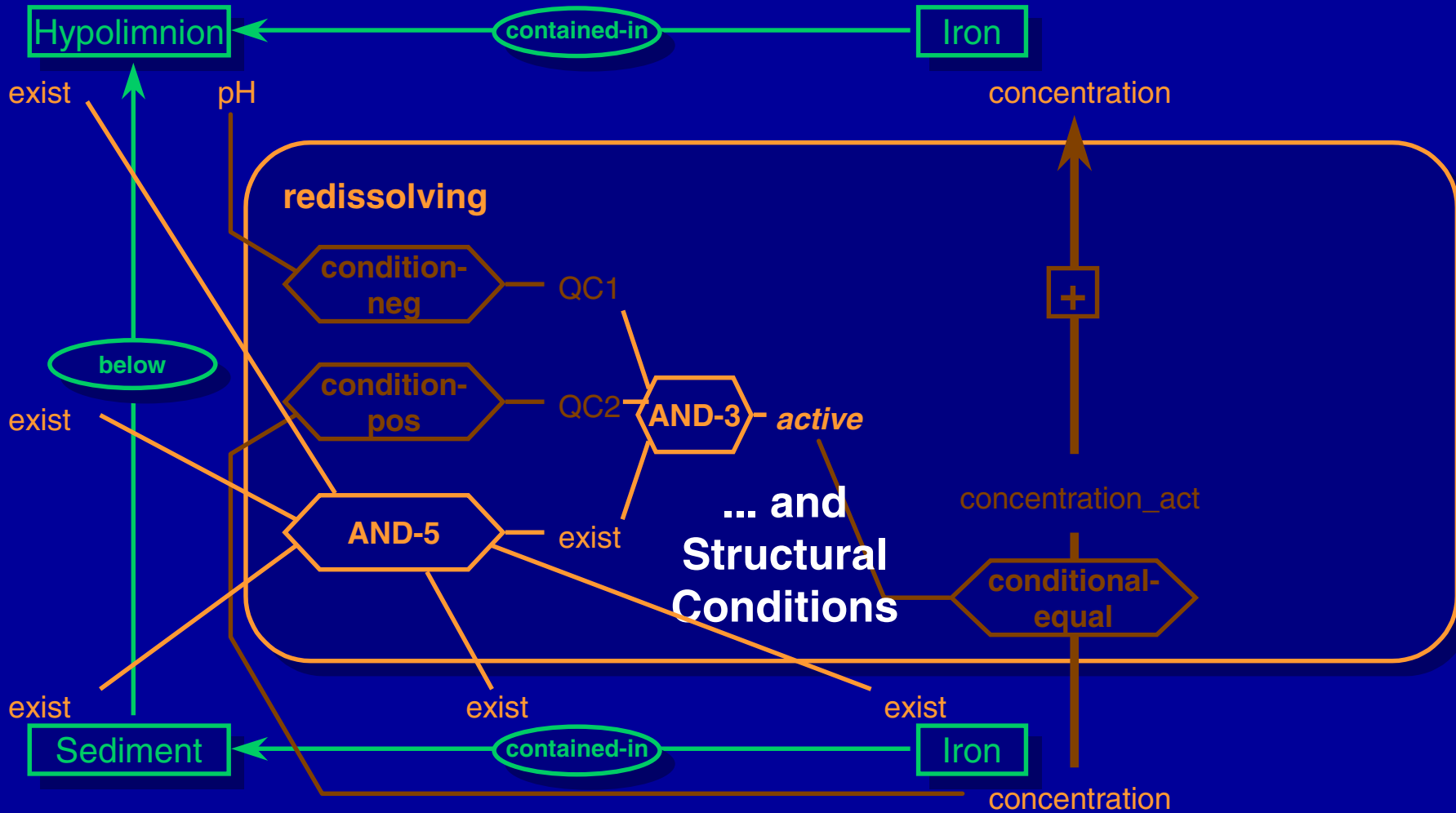
Example - Details of Conditions and Effects



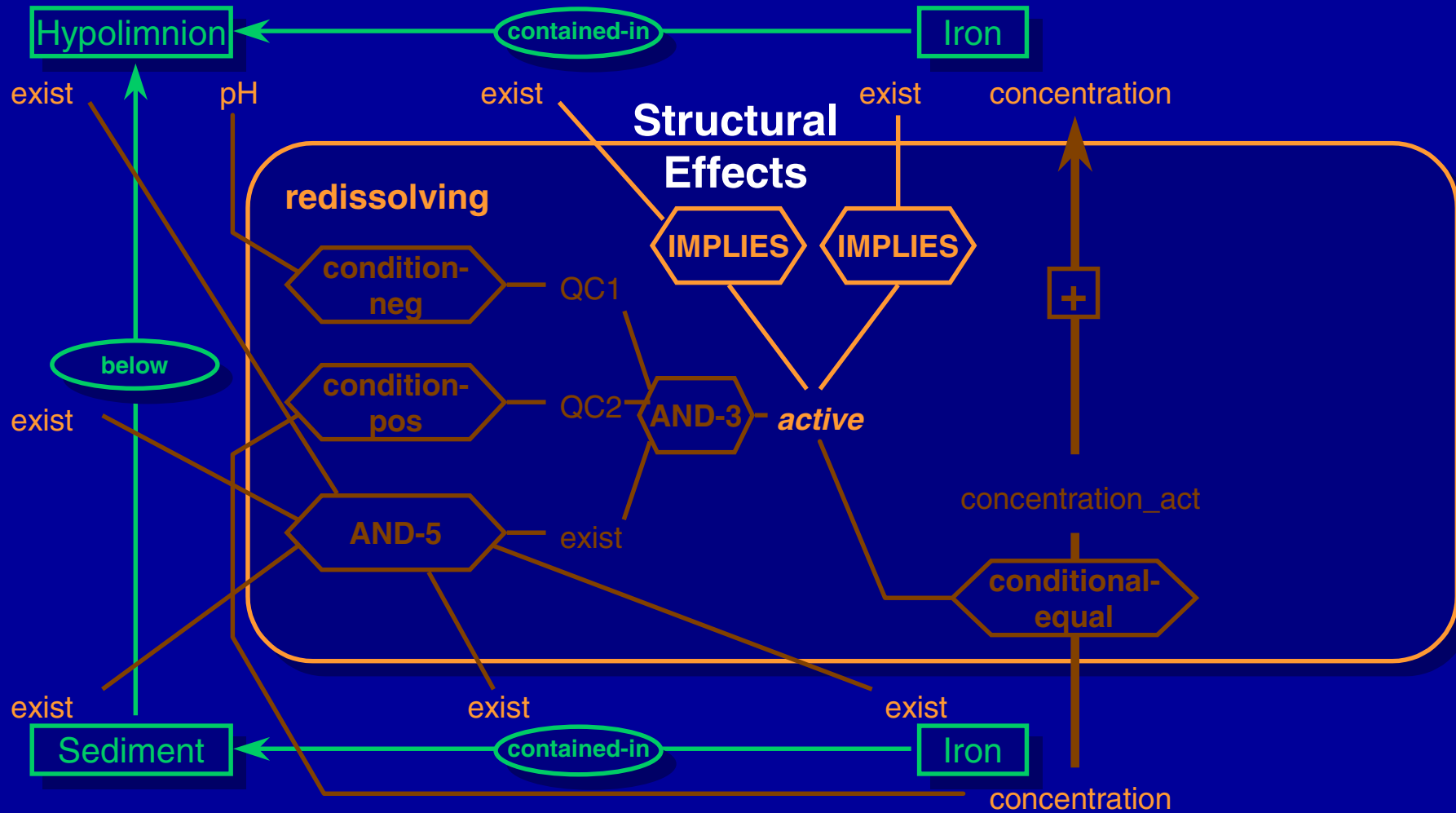
Example - Details of Conditions and Effects



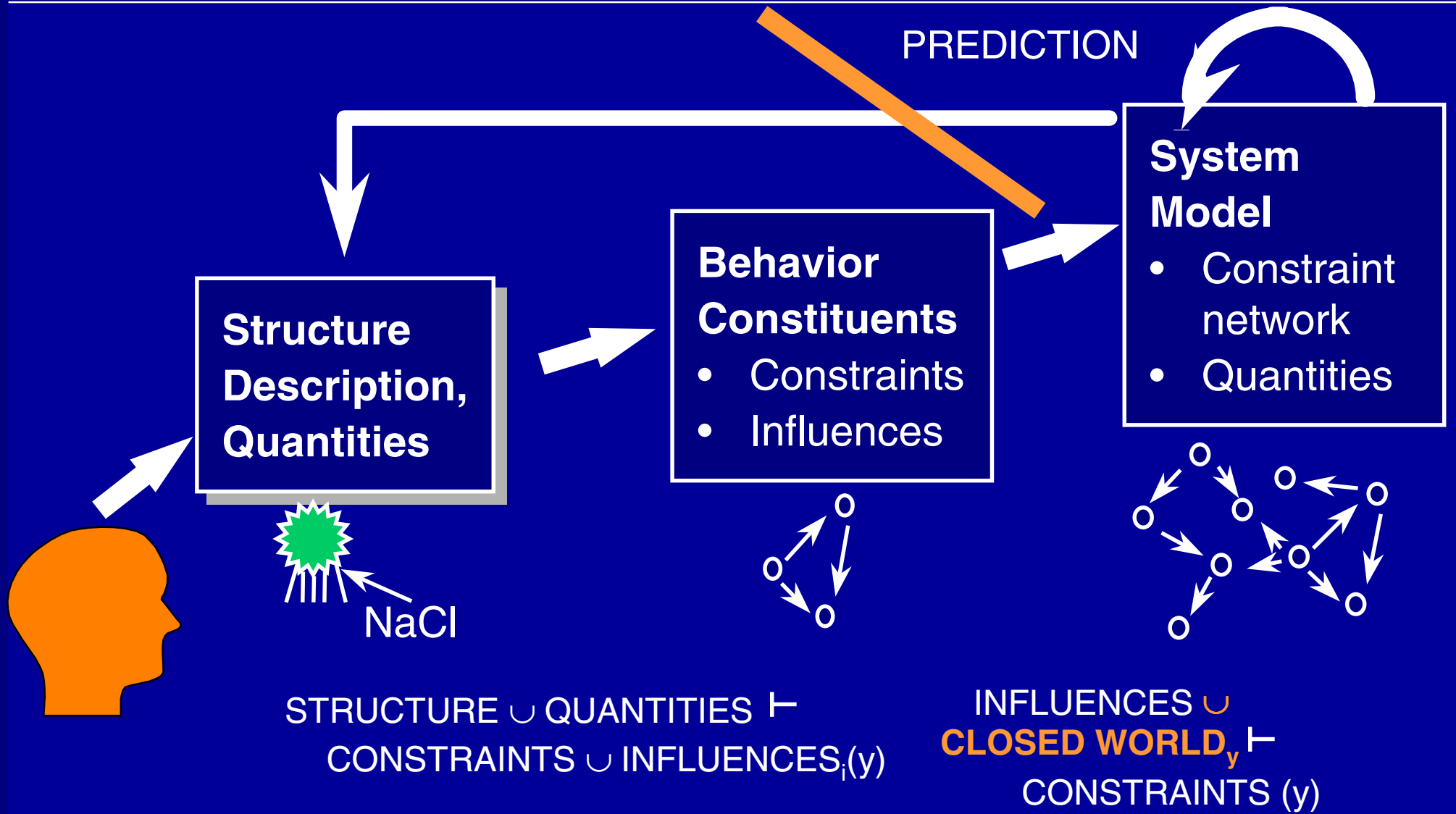
Example - Details of Conditions and Effects



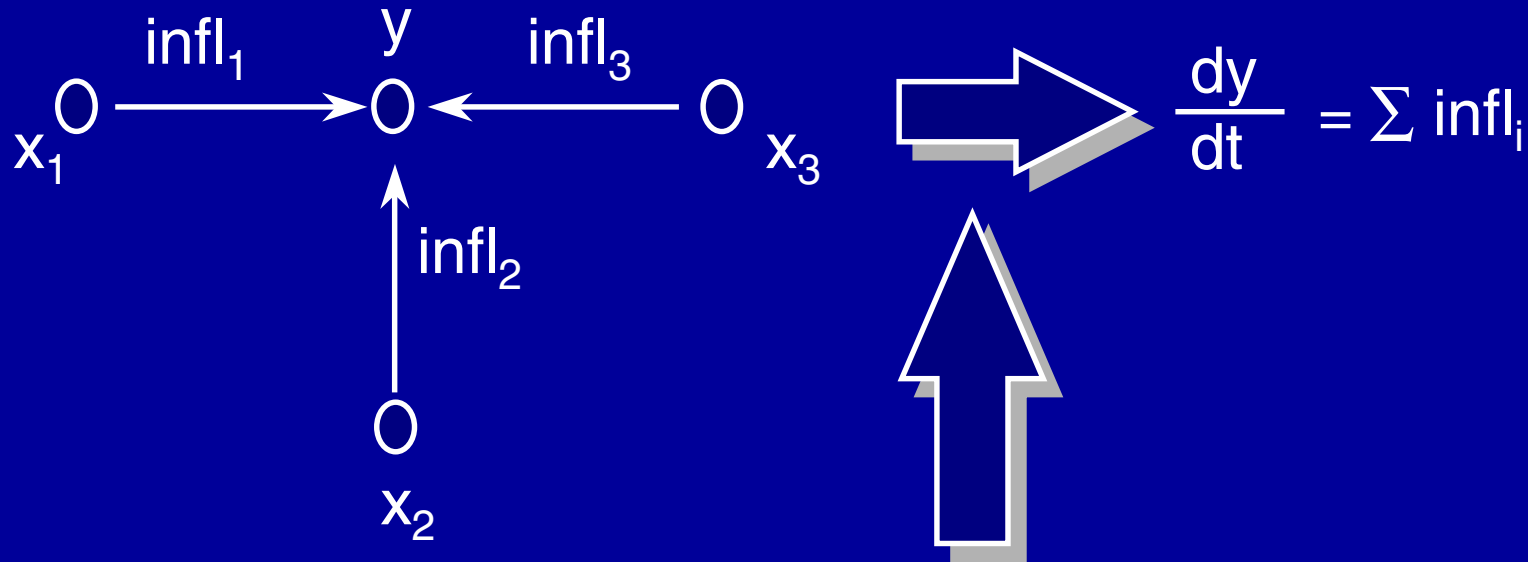
Example - Details of Conditions and Effects



Model Generation



Resolving Influences



CLOSED WORLD
ASSUMPTION_y

Tasks: Situation Assessment

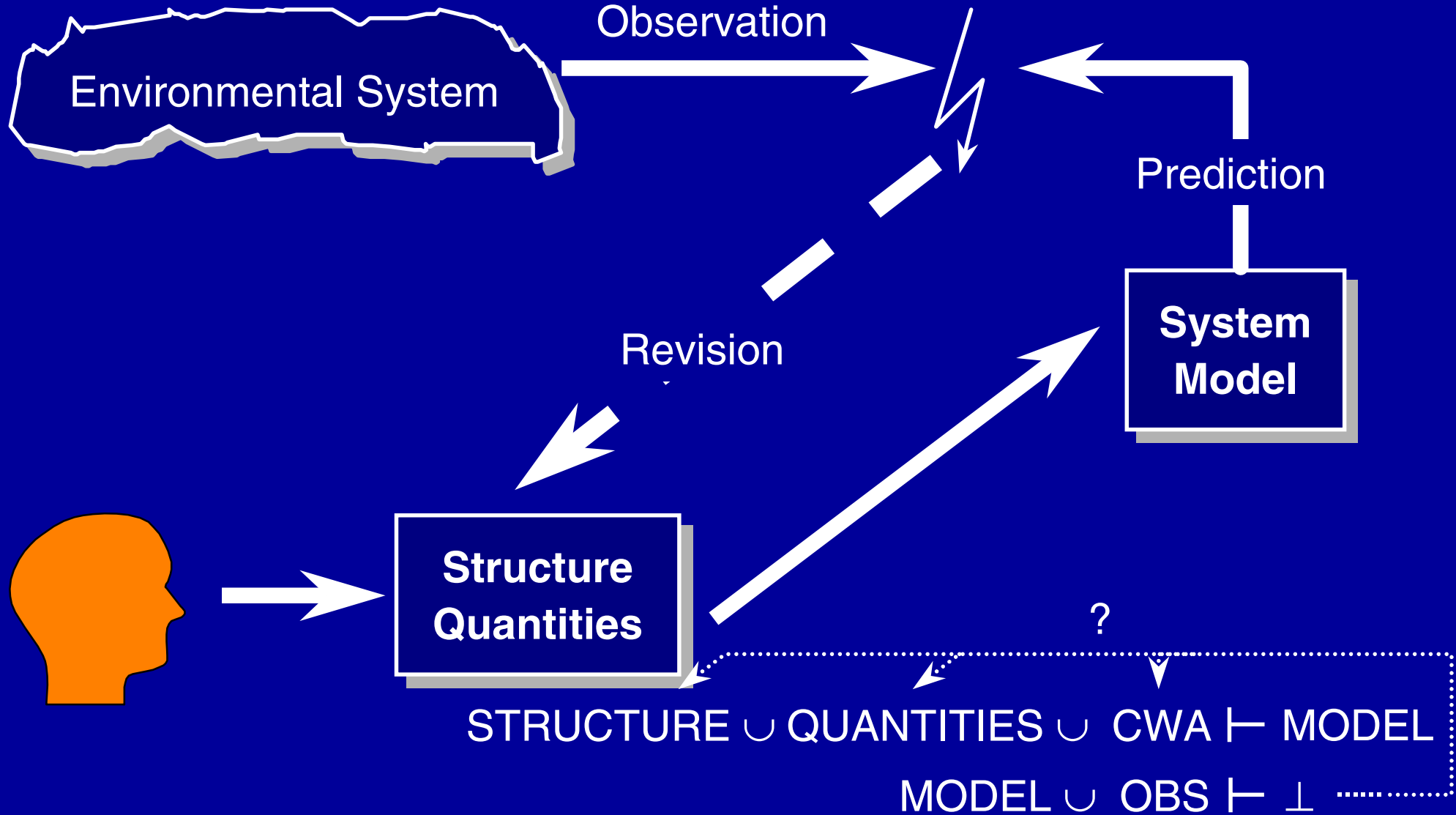
In area x , trees of specifier y shed their leaves at an unusual rate - what's going on?

OBS → SYSTEM SITUATION

Determine

- relevant constituents and their relationships and parameters
- their current state: values of variables
- that collectively account for the observation

We May Be Wrong - Model Revision



Searching for Revisions

Assumptions to be revised:

$obj_i,$

$obj-rel_j,$

$var_k = val_l,$

CWA_n

Model_{rev}

**Domain Theory
(Library)**

$obj-type, var-type$

$beh-const_1$

$beh-const_2$

...

Conditions

obj_1

obj_2

$obj-rel_3$

obj_4

Specification of Revisables

$$SD = SD_{rev} \cup SD_{fix}$$

- We **know** (based on observations) something about the domain, the system, the state
- We **assume** some things about the system (objects and relations), the state

E. g. for situation assessment:

$$OBS \subset QUANT_{fix} \subset SD_{fix}$$

$$SD_{rev} = STRUCT_{rev} \cup QUANT_{rev}$$

Situation Assessment: Formalization

What Does not Fit the Observations?

- $\text{MODEL}_0 \cup \text{OBS} \vdash \perp$
→
- $\text{MODEL}_1 \cup \text{OBS} \not\vdash \perp$
or →
- $\text{MODEL}_1 \vdash \text{OBS}$

System Identification

- $\text{MODEL}_{\text{rev}} = \text{STRUCTURE}_{\text{rev}} \cup \text{PAR-SPEC}_{\text{rev}} \cup \text{CWA}$

State Identification

- $\text{MODEL}_{\text{rev}} = \text{VAR-SPEC}_{\text{rev}}$

Diagnosis: Formalization

What Causes Violation of Goals?

- $\text{MODEL}_1 \cup \text{GOALS} \vdash \perp$
→
- $\text{MODEL}_2 \cup \text{GOALS} \not\vdash \perp$
or →
- $\text{MODEL}_2 \vdash \text{GOALS}$

Revisable: What Can Be **Influenced**?

- $\text{MODEL}_{\text{rev}} = \text{STRUCTURE}_{\text{rev}} \cup \text{VAR-SPEC}_{\text{rev}} \cup \text{CWA}$

Tasks: Therapy Generation

Having identified possible causes of the mangrove degradation - what can be done?

GOALS → REMEDIATE
ACTIONS

Determine

- responsible factors that can be influenced
- actions that create appropriate influences

Therapy Generation: Formalization

What Can Reach the Goals?

- $\text{MODEL}_1 \cup \text{GOALS} \vdash \perp$
→
- $\text{MODEL}_1 \cup \text{ACTIONS} \cup \text{GOALS}' \not\vdash \perp$
or →
- $\text{MODEL}_1 \cup \text{ACTIONS} \vdash \text{GOALS}'$

- Actions as unconditioned processes
- Intermediate goals may be different from ultimate ones
- Goals may be revised

Reconstructing the Standard (Component-based) Approach

- **Object types:** Component types, terminal types
- **Object relation types:** connected (terminal, terminal)
part-of (terminal, component)
- **Quantity associations:** Variables for terminal types,
modes for components
- **Behavior constituents:** ok and fault models
(and terminal identification)
(IC: component-type, AC: mode)
- **Structure:** connection and part-of structure
- **State:** (terminal) variable values



GOAL \Leftrightarrow {ok(C_i)}

Even More Ambitious: Model-guided Discovery

- Revise the domain theory (model fragment library)

