Requirements Models:

- The Why-What-How model
- The 4-Variable model
- The Reference model
- The Goal-Service-Constraint model
- The 4-World model
What is RE?

What are requirements?

"... Requirements definition is a careful assessment of the needs that a system is to fulfill.

It must say why a system is needed,

   based on current and and foreseen conditions,
   which may be internal operations or an external market

It must say what system features will serve and satisfy this context.

And it must say how the system is to be constructed ..."

[Ross77]

Not about the design
What is RE?

What are requirements?

why?  ✶ Enterprise requirements

for "context analysis" - the reasons why the system is to be created.
(e.g., why IS for BPR, organizational structure, agents, goals)

constraints on the environment in which the system is to function
(e.g., airplane running beyond runway, AT&T Internet service)

the meaning of system requirements
(symbols, relationships, ontology, vocabulary)

what? ✶ (System) functional requirements

a description of what the system is to do;
what information needs to be maintained?
what needs to be processes?
{f: I -> O}

how? ✶ (System) non-functional requirements

(global) constraints on how the system is to be constructed and function.
E.g., -ilities and -ities
{bcfh(f: I -> O)}
The 4-Variable Model

(the functional documentation model)

S - Specification of software in terms of inputs & outputs

(possibly large in number, and in very complex relationships)
The 4-Variable Model

(the functional documentation model)

The system involves input and output devices, monitored variables, controlled variables, software, and environment. The specification of software in terms of inputs and outputs can be large and complex.

**NAT(m, c):** describes nature without making any assumptions about the system;

**REQ(m, c):** describes the desired system behavior;

**IN(m, i):** relates the monitored real-world values to their corresponding internal representation;

**OUT(o, c):** relates the software-generated outputs to external system-controlled values; and

**SOF(i, o):** relates program inputs to program outputs.

Any issues?

**Nat** - the range of sounds detected or non-detected by the sensor and the possible range of values of the actuator controlling the buzzer.

**Req** - A warning that notifies the nurse if the system detects heart stops beating. The document’s formalization: if the sound being monitored falls below a certain threshold, then the system sound the buzzer.

**In** - The input registers holding the data read from the sensor monitoring the sounds of the heart beat.

**Out** - The output registers which are read by the actuator that can sound the buzzer.

**SOF** - If the input register doesn’t show signs of a heart beat for more than some specified time then the output register indicates the alarm to ring.
What are requirements?

[P. Zave and M. Jackson, Four Dark Corners of Requirements Engineering. ACM Transactions on Software Engineering and Methodology 6(1) 1-30. ACM Press. 1997]

**The WRSPM Model**

- **D – Domain Properties**
  - (world, enterprise, business, domain theory)
- **R – Requirements**
- **S – Specification**
- **C – Computer**
- **P – Program**

**Domain Properties:** (indicative, = assumptions=domain knowledge)
things in the environment (application domain) that are true regardless of the proposed system

**Requirements:** (optative)
things in the application domain that we wish to be made true through the proposed system

"Many phenomena not accessible by the machine"

**Specification:**
a description of the behaviors that the program must have in order to meet the requirements

"Can, and should, only be written in terms of shared phenomena"

**Designated Terminology** – names/vocabulary to describe W, (R), S, M in terms of phenomena – typically states or events

\[
e = e_h \cup e_v
\]
\[
e_h \cap e_v = \Phi
\]
\[
s = s_v \cup s_h
\]
\[
s_v \cap s_h = \Phi
\]
Requirements should contain *nothing but* information about the environment.


**D – Domain Properties**
*World, Enterprise, Business, Domain theory*

**R – Requirements**
phenomena/things not observable by machine ($e_h$)

**S – Specification**
shared phenomena/things
- domain-controlled ($e_v$)
- machine-controlled ($s_v$)

**C – Computer**
phenomena/things not observable by domain ($s_h$)

**P – Program**

<table>
<thead>
<tr>
<th>indicative</th>
<th>optative</th>
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<tbody>
<tr>
<td>$e_h$</td>
<td>✓</td>
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<tr>
<td>$e_v$</td>
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<tr>
<td>$s_v$</td>
<td>✓</td>
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**The WRSPM Model**

**W, R** - uses {$e_h, e_v, s_v$}

**P, M** - uses {$e_v, s_v, s_h$}

**S** - uses {$e_v, s_v$}

- **R**equirements describe what is observable at the interface between the environment and the machine – hence exist only in the environment;
- Anything else is regarded as implementation bias;
- **S**tates in **S**pecifications should describe states of the environment – hence, specification languages intended to describe internal (program) states of the machine are inadequate.

**Consequences**
- Freedom to collect and record information about the environment even before we are sure it will be needed (i.e., *no minimality restriction - there must be nothing that is not necessary to carry out the currently proposed machine functions.*);
- Designations refer to the real *W*orld, and *m*achine states may have NO direct correspondence to it.

**Verification:** $S, D \models R \quad P, C \models S$
What are requirements?

Example 6: Coffee Machine

- **D1**: Before the switch is moved to the On position, the user must add ground coffee to the filter and insert it in the coffee machine.
- **D2**: Before the switch is moved to the On position, the user must add water to the reservoir.
- **R1**: When the user moves the three-way switch to the On position, coffee shall be brewed.

**S1**: If the three-way switch is On, the coffee brewer shall be actuated.

**C**: with a switch as a sensor and a brewer as an actuator

**P**: Program

**Designation Categories:**
- $e_h$: ?
- $e_v$: ?
- $s_v$: ?
- $s_h$: ?
What are requirements?

Example 1: Patient Monitoring

D1: There will always be a nurse close enough to hear the buzzer
D2: The sound from the heart falling below a certain threshold indicates that heart has (is about to) stop
R1: A warning system notifies the nurse if the patient’s heartbeat stops

S1: If the sound from the sensor falls below a certain threshold, the buzzer shall be actuated
C – with a microphone as a sensor and a buzzer as an actuator
P - Program

Designation Categories:

$e_h$: the nurse and the heartbeat of the patient.
$e_v$: sounds from the patient’s chest.
$s_v$: the buzzer at the nurse’s station.
$s_h$: internal representation of data from the sensor.

What if the domain assumptions are wrong?
What are requirements?

Example 1: Patient Monitoring

- D1: There will always be a nurse close enough to hear the buzzer
- D2: The sound from the heart falling below a certain threshold indicates that heart has (is about to) stop
- S1: If the sound from the sensor falls below a certain threshold, the buzzer shall be actuated
- R1: A warning system notifies the nurse if the patient’s heartbeat stops

C – with a microphone as a sensor and a buzzer as an actuator

P - Program

What?

S, D ⊨ R

P, C ⊨ S
"... Requirements Engineering is the branch of Systems engineering concerned with real-world goals for, services provided by, and constraints on software systems. Requirements engineering is also concerned with the relationships of these factors to precise specifications of system behavior and to their evolution over time and across system families..."  

[Zavc94]
What to elicit?

Four Worlds of RE

Enterprise Model

*Subject World*
- FRs, NFRs
- Problem Domain
- Accountants, bankers, loan mgrs

*System World*
- System) FRs, NFRs

*User World*
- FRs, NFRs
- Tellers, clients, mgrs...

*Developer World*
- FRs, NFRs
- Analysts, specifiers, designers, mgrs...
How does this relate to RE process?
Four Worlds of RE for Control Systems

- **Usage System**: Needs to ensure safe control of Subject system.
- **Control System**: Tracks and controls the state of Subject system.
- **Development System**: Contracts with Usage System and builds Control System.
The Why-What-How Model

D – Domain Properties
(World, Enterprise, Business, Domain theory)

R – Requirements

S – Specification

C – Computer Program

P – Program

The WRSPM Model

Recall: Models about Requirements Revisited

W, \(R\) uses \{e_{hv}, e_{v}, s_{h}\}

P, \(M\) uses \{e_{v}, s_{v}\}

S uses \{e_{v}, s_{v}\}

The Why-What-How Model

Requirements should contain nothing but information about the environment.

The 4-variable model:

\[ M \xrightarrow{REQ} C \xleftarrow{OUT} \]

\[ IN \xrightarrow{SOF} O \]

The goal-service-constraint model:

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Does the reference model capture all the above?
Where are goals, services and constraints? [Zave94]
Which is about \(S, D \models R\)?
Which is about technical feasibility, component reuse, etc.?
Where is traceability?
Boundaries are not fixed

Example 1: Elevator control system

E.g. Add some sensors to detect when people are waiting. This changes the nature of the problem to be solved.
An Integrated Model

-Ross:
  - why (context – Environment/Enterprise, Domain, Business, World)
  - what (Fn)
  - how (NFn)

- Reference model: W/D. R. S

- Zave: Goal

More models & Goal-orientation – these later in Elicitation & Modeling)
Some Questions
Revisiting the Reference Model

Any issues with this requirement?

D1: There will always be a nurse close enough to hear the buzzer
D2: The sound from the heart falling below a certain threshold indicates that heart has (is about to) stop
R1: A warning system notifies the nurse if the patient's heartbeat stops
Any issues with this requirement?

D1: There will always be a nurse close enough to hear the buzzer
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S1: If the sound from the sensor falls below a certain threshold, the buzzer shall be actuated

C – with a microphone as a sensor and a buzzer as an actuator

P - Program

What if a warning system notifies the nurse one year after the patient’s heartbeat stops?

Is this warning system really what we want?
Boundaries are not fixed

Example 1: Elevator control system

- people waiting
- people in the elevator
- people wanting to go to a particular floor
- elevator motors
- safety rules
- elevator call buttons
- floor request buttons
- current floor indicators
- motor on/off
- door open/close
- scheduling algorithm
- control program

Things not observable by machine:
- things not observable by domain
- shared things
  - domain-controlled
  - machine-controlled

E.g. Add some sensors to detect when people are waiting
This changes the nature of the problem to be solved

Example 2: The 4-variable model

Environment

- Input Devices
  - Monitored variables

Software

- output data

Output Devices

- Controlled variables

Environment

S - Specification of software in terms of inputs & outputs
(possibly large in number, and in very complex relationships)

Systems engineer decides:
- what application domain phenomena are shared
- the boundaries by designing the input/output devices
- I/O data as proxies for the monitored and controlled variables
Boundaries are not fixed

- Consider coffee brewing machine
- Consider patient monitoring system
¡MUCHAS GRACIAS!
Appendix
What are requirements?

Example 2: Traffic lights

D1: Drivers stop at red lights
D2: Pedestrians walk when green
R1: Allow pedestrians to cross the road safely

S1: Show a red light to the cars and a green light to the pedestrians

Example 3: Traffic Lights - Safety

D1. Drivers stop at red lights
D2. Pedestrians stop at red lights
D3. Drivers drive at green lights
D4. Pedestrians walk when green

R1: Pedestrians and cars cannot be in the intersection at the same time

S1: Never show a green light to both pedestrians and cars

What if the domain assumptions are wrong?
What are requirements?

Example 4: Aircraft Control

- D1: Wheel pulses on if and only if wheels turning
- D2: Wheels turning if and only if moving on runway
- R1: Reverse thrust shall only be enabled when the aircraft is moving on the runway

S1: Reverse thrust enabled if and only if wheel pulses on

Example 5: Security

- D1: Authorized personnel have passwords
- D2: Passwords are never shared with non-authorized personnel
- R1: The database shall only be accessible by authorized personnel

S1: Access to the database shall only be granted after the user types an authorized password

What if the domain assumptions are wrong?
What Are Requirements?

Example 7: In a single-customer banking environment,

- **deposit**(*a*, *m*): *a* is an action in which amount *m* is deposited
- **withdrawal-request**(*a*, *m*): *a* is an action in which a withdrawal of amount *m* is requested
- **withdrawal-payout**(*a*, *m*): *a* is an action in which amount *m* is paid out as a withdrawal
- **balance**(*b*, *p*): during pause *p* the balance is amount *b*;

At any time, the balance is equal to the sum of the amounts of all the previous deposits, minus the sum of the amounts of all the previous withdrawal payouts:

\[
(\forall b, p \mid : balance(b, p) = (b = (+m \mid (\exists a \mid : deposit(a, m) \land earlier(a, p)) : m)) - (+m \mid (\exists a \mid : withdrawal-payout(a, m) \land earlier(a, p)) : m)))
\]

A withdrawal request leads to a withdrawal payout, if the requested amount is less then the current balance

\[
(\forall a, m, p, b \mid : withdrawal-request(a, m) \land ends(a, p) \land balance(b, p) \land b \geq m:
(\exists a' \mid : withdrawal-payout(a', m) \land earlier(a, a'))) \]

- **S** – a requirement (**R**), which is implementable, hence a specification

\[
(\forall a, m, p \mid : withdrawal-request(a, m) \land ends(a, p) \land \exists m \leq
((+m \mid (\exists a \mid : deposit(a, m) \land earlier(a, p)) : m)) - (+m \mid (\exists a \mid : withdrawal-payout(a, m) \land earlier(a, p)) : m)):
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[Ross 77]

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<thead>
<tr>
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<tr>
<td>E/D/B/W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
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</tbody>
</table>

$M^g, Prog^g \models S^g; S^g, D^g \models R^g; R^g, D^g \models G; (G \models \neg P) \lor (G \models \neg P)$
G: goals
R: a model of the requirements
D: a model of the environment
S: a model of the sw behavior

 evolution

softgoal satisficing

\[
M^G, \text{Prog}^G \models S^G; S^G, D^G \models R^G; R^G, D^G \models G; (G \models \neg P) \lor (G \models \neg \neg P)
\]