

8. More on Requirements: The EARS approach

(mainly borrowed from David Pereira)

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The EARS Approach to Requirements Specification

What is EARS?

- The acronym **EARS** stands for "*Easy Approach to Requirements Syntax*"
- EARS is a mechanism to gently constrain textual requirements
- EARS patterns provide structured guidance that enable authors to write high quality textual requirements.

Building Blocks

- There is a set syntax (structure), with an underlying set of rules.
- A small number of keywords are used to denote the different patterns of an EARS requirement.
- The clauses are always in the same order, following temporal logic.
- The syntax and the keywords closely match common usage of English and are therefore intuitive.

Context

- **When:** while the author and colleagues at Rolls-Royce PLC were analysing the airworthiness regulations for an engine jet control system.
- **"Inputs":** The regulations contained high level objectives, a mixture of implicit and explicit requirements at different levels, lists, guidelines and supporting information.
- **How?:**
 - In the process of extracting and simplifying the requirements, Mav noticed that the requirements all followed a similar structure.
 - He found that requirements were easiest to read when the clauses always appeared in the same order. These patterns were refined and evolved to create EARS.
- **Inception:** The notation was first published in 2009 and has been adopted by many organisations across the world.

Why adopt EARS?

- System requirements are usually written in unconstrained natural language, which being to the table its inherent imprecision and ambiguity.
- It is not unusual that authors of requirements have no training on how to write requirements.
- During system development, requirements problems propagate to lower levels.

This creates unnecessary volatility and risk, impacting schedules and costs.

Why adopt EARS?

- EARS reduces or even eliminates common problems found in natural language requirements.
- It is especially effective for requirements authors who must write requirements in English, but whose first language is not English.
- EARS has proved popular with practitioners because it is lightweight, there is little training overhead, no specialist tool is necessary, and the resultant requirements are easy to read.

In the words of the author, "**(...) because the EARS method imposes just a slight constraint on natural language while providing a simple, logical method for constructing clear, concise, unambiguous requirements."**

Who is using EARS?

- the EARS methodology was first presented to the 17th IEEE International Requirements Engineering Conference in 2009
- since then, it has been adopted by numerous organizations (Bosch, Honeywell, Intel, Rolls-Royce and Siemens) and included in the requirements engineering curricula of many other universities (China, France, Sweden, UK, USA).

The EARS Patterns

Vocabulary

<system> the system name (only 1 per requirement)

<response> the system response (1 or more per requirement)

<pre> a precondition, *i.e.*, a set of properties from a state that need to be true for the requirement to be active (zero or many per requirement)

<trigger> the trigger that activates a requirement (zero or one per requirement)

<feature> a feature of the system (zero or one)

Specific keywords

while, when, where, if, then, the, shall... we will see in a moment when and where they are used.

Ubiquitous
the <system> shall <response>
State Driven
while <pre(s)> the <system> shall <response>
Event Driven
when <trigger> the <system> shall <response>
Unwanted Behaviour
if <trigger> then the <system> shall <response>
Optional Feature
where <feature> the <system> shall <response>

Ubiquitous requirements

These refer to requirements that must be always active during system operation.

the <system> shall <response>

Moreover:

- typically state fundamental aspects of the system
- No EARS specific keyword is present when specifying this particular type of requirement.
- Which makes sense! These requirements do not depend on pre-condition(s) or triggers to become active. They must remain active all the time.

Example

- **the** distances computed between two sets of coordinates **shall** account for curvature of the earth
- **the** compiler **shall** transform source code into semantically equivalent binary code
- **the** surveillance UAV **shall** fly only inside of the designated flight zone
- **the** software package **shall** contain an installer
- **the** software **shall** be written in programming language X

State driven requirements

These are requirements that are active as long as the specified state, hereby represented by a pre-condition, remains true. These requirements start with the keyword while.

Syntactic pattern

```
while <pre(s)> the <system> shall  
      <response>
```

Example

- **while** there is no card in the ATM **the** ATM **shall** display "insert card to begin".
- **while** in maintenance mode **the** kitchen system **shall** reject all input.
- **while** in Low Power Mode **the** software **shall** keep the display brightness at the Minimum Level
- **while** the heater is on **the** software **shall** close the water intake valve
- **while** the autopilot is engaged **the** software **shall** display a visual indication to the pilot

Event driven requirements

Event driven requirements are initiated **when** a trigger occurs or is detected. They are denoted by the keyword **when**.

Syntactic pattern

```
when <trigger> the <system> shall  
      <response>
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Simple translation exercise

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Simple translation exercise

Original req: *In the event of a fire, the security system shall unlock the fire escape doors*

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Syntactic pattern

```
when <trigger> the <system> shall  
      <response>
```

Simple translation exercise

Original req: *In the event of a fire, the security system shall unlock the fire escape doors*

In EARS: **when** a fire is detected **the** security system **shall** unlock the fire escape doors

Examples of Event Driven Requirements

Example

- **when** mute is selected **the** laptop **shall** suppress all audio output.
- **when** potato is inserted into the input hatch **the** kitchen system **shall** peel the potato.
- **when** continuous ignition is commanded by the aircraft **the** control system **shall** switch on continuous ignition
- **when** an unregistered device is plugged into a USB port **the** OS **shall** tries to locate and load the driver for the device.
- **when** the water level falls below the Low Water Threshold **the** software **shall** open the water valve to fill the tank to the High Water Threshold

Optional feature requirements

Optional feature requirements apply in products or systems that include the specified feature and are denoted by the keyword Where.

Syntactic pattern

```
where <feature> the <system> shall  
      <response>
```

Example

- **where** the car has a sunroof **the** car **shall** have a sunroof control panel on the driver door.
- **where** the kitchen system has a food freshness sensor **the** kitchen system **shall** detect rotten foodstuffs.
- **where** a thesaurus is part of the software package **the** installer **shall** prompt the user before installing the thesaurus
- **where** hardware encryption is installed **the** software **shall** encrypt data using the hardware instead of using a software algorithm
- **where** a HDMI port is present **the** software **shall** allow the user to select HD content for viewing

Unwanted behaviour requirements

These are used to specify the required system response to undesired situations and are denoted by the keywords if and then.

Syntactic pattern

```
if <trigger> then the <system> shall <response>
```

A note on "trigger"

As in the case of event requirements, for unwanted behaviours one needs to identify the trigger/event. It is on you, the requirement specification responsible to understand if it refers to something wanted or unwanted. EARS just ensures a syntactic distinction, i.e., using **when** or **if** depending on the concrete case.

Example

- **if** an invalid credit card number is entered **then the** website **shall** display "please re-enter credit card details"
- **if** a spoon is inserted to the input hatch **then the** kitchen system **shall** eject the spoon
- **if** the memory checksum is invalid **then the** software **shall** display an error message
- **if** the ATM card inserted is reported lost or stolen **then the** software **shall** confiscate the card
- **if** the measured and calculated speeds vary by more than 10% **then the** software **shall** use the measured speed

Syntax of a complex EARS requirement

Is the more general pattern of requirement that exists in EARS. It uses a combination of EARS keywords to allow for such complexity.

Syntactic pattern

```
<multiple conditions> the <system> shall <response>
```

such that **multiple conditions** is a combination of:

- a pre-condition, using the **while** keyword
- a trigger, using the **when** keyword
- an unwanted condition, using the **if** keyword
- a specific feature, using the **where** keyword

Example

- **while** the aircraft is on ground **when** reverse thrust is commanded **the** engine control system **shall** enable reverse thrust
- **while** a second optical drive is installed **when** the user selects to copy disks **the** software **shall** display an option to copy directly from one optical drive to the other optical
- **while** in start up mode **when** the software detects an external flash card **the** software **shall** use the external flash card to store photos
- **when** the landing gear button is pressed once **if** the software detects that the landing gear does not lock into position **then the** software **shall** sound an alarm

Rewriting Requirements Using EARS

Examples on how to use EARS for rewriting requirements

Original Requirement

The installer software shall be available in Portuguese.

Type of Requirement

Ubiquitous

Requirement using EARS

the installer software **shall** be available in Portuguese

Original Requirement

The software shall display a count of the number of participants.

Type of Requirement

Event Driven

Requirement using EARS

when the user selects the caller count from the menu **the** software **shall** display a count of the number of participants in the audio call in the user interface

Original Requirement

The software shall phone the Alarm Company.

Type of Requirement

Unwanted Behavior

Requirement using EARS

if the alarm software detects that a sensor has malfunctioned **then the** alarm software **shall** phone the Alarm Company to report the malfunction

Original Requirement

The software shall mute the microphone.

Type of Requirement

State Driven

Requirement using EARS

while the mute button is pressed **the** software **shall** mute the microphone

Examples on how to use EARS for rewriting requirements

Original Requirement

The software shall download the book without charge

Type of Requirement

Optional Feature Requirement

Requirement using EARS

where the book is available in digital format **the** software **shall** allow the user to download the book without charge for a trial period of n days

Original Requirement

The software shall warn the user of low battery

Type of Requirement

Complex Requirement

Requirement using EARS

while on battery power **if** the battery charge falls below 10% remaining **then the** system **shall** shall display a warning message to switch to AC power

Ex. 8.1: Rewrite using EARS patterns

1. The user can have **tea** after having 2 consecutive **coffees**.
2. It is possible to do **a** after 3 **b**'s, but not more than 1 **a**.
3. It must be possible to do **a** after [doing **a** and then **b**].
4. If a taxi is **allocated** to a service, it must first **collect** the passenger and then **plan** the route.
5. On detecting an **emergency** the taxi becomes inactive.
6. The user **can have coffee** after the **coffee button** is pressed.
7. The user **must have coffee** after the **coffee button** is pressed.
8. It is always possible to **turn off** the coffee machine.
9. It is always possible to reach a state where the coffee machine can be **turned off**.
10. It is never possible to **add chocolate** right after pressing the *latte button*.

Requirement 1

The user can have tea after having 2 consecutive coffees

Type

Event Driven

Rewritten in EARS

when the user takes two consecutive coffees **the** machine **shall** be able to serve tea to the user

Requirement 2

It is possible to do *a* after 3 *b*'s, but not more than 1 *a*

Type

Two event driven requirements

Rewritten in EARS

This requirement must be split in two before being written using EARS patterns:

- **when** three *b*'s are done **the** system **shall** allow the user to do one *a*
- **when** three *b*'s and one *a* were done **the** system **shall** not allow the user to do another *a*

Requirement 3

It must be possible to do *a* after [doing *a* and then *b*].

Type

Event Driven

Rewritten in EARS

when *a* was done followed by a *b* **the** system **shall** allow the user to do *a*

Requirement 4

If a taxi is **allocated** to a service, it must first **collect** the passenger and then **plan** the route.

Type

Two requirements: one Event Driven and one Complex

Rewritten in EARS

- **when** allocated to a service **the** taxi **shall** collect the associated passenger
- **while** allocated to a service, **when** it has collected the passenger **the** taxi **shall** plan the route

Requirement 5

On detecting an **emergency** the taxi becomes inactive.

Type

Event Driven

Rewritten in EARS

when an emergency is detected **the** taxi **shall** become inactive

Requirement 6

The user **can have coffee** after the **coffee button** is pressed.

Type

Event Driven

Rewritten in EARS

when the coffee button is pressed **the** coffee machine **shall** be able to serve coffee

Requirement 7

The user **must have coffee** after the **coffee button** is pressed.

Type

Two event driven requirements

Rewritten in EARS

- **when** the coffee button is pressed **the** coffee machine **shall** serve a coffee
- **when** a coffee is served **the** user **shall** drink that coffee

Requirement 8

It is always possible to **turn off** the coffee machine.

Type

Ubiquitous

Rewritten in EARS

the coffee machine **shall** have a mechanism to shutdown at any time during operation

Requirement 9

It is always possible to reach a state where the coffee machine can be **turned off**.

Type

Ubiquitous

Rewritten in EARS

the coffee machine **shall** always be able to reach a state where it is possible to safely shutdown

Requirement 10

It is never possible to **add chocolate** right after pressing the *latte button*

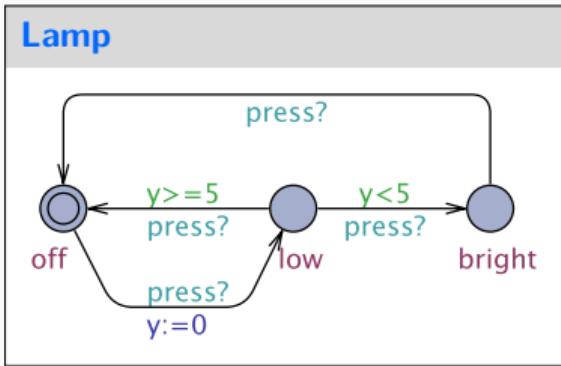
Type

Complex: state driven + unwanted behavior

Rewritten in EARS

while the machine is preparing a latte **if** chocolate button is pressed **then the** machine **shall** not add chocolate to the latte

Exercise: more formulas, seen with Uppaal's CTL



Ex. 8.2: Rewrite requirements in EARS, and identify their type

1. The lamp can become bright;
2. The lamp will eventually become bright;
3. The lamp can never be on for more than 3600s;
4. It is possible to never turn on the lamp;
5. Whenever the light is bright, the clock y is non-zero;
6. Whenever the light is bright, it will eventually become off.

Applying and Troubleshooting EARS

How to apply EARS

- Identify whether you are working with a requirement, or something else (e.g., note, example, remark, etc)
- Identify compound requirements, i.e., whether the requirement needs to be split/decomposed
- Identify the acting system, person, or process
- Analise the needed sentence type(s)
- Identigy possible missing requirements
- Analyse the translated requirements for ambiguity, conflict, and repetition
- Review requirements if possible
- Interate as required

What are the issues that can occur when using EARS?

- *No sentence type fits*: are you actually trying to translate a requirement?
- *Can't identify the actor*: either use higher abstraction level until it makes sense, or get more information from the relevant stakeholder
- *There is no system response*: typically the case with non-functional requirements; it can be expressed as "the system shall be ..."
- *There is no template for "shall not"*: try using "shall be immune" or similar or, as last resort, use the "shall not" pattern

Some exercises for training with EARS

The problem

A farmer wants to transport a fox, a goose, and some beans across a river (from the left margin to the right margin). Unfortunately, he can only carry one at a time. Furthermore, if the farmer is not present, the fox will eat the goose and the goose will eat the beans.

Ex. 8.3: Identify requirements

The goal of this exercise is for you to identify the requirements for this problem, and classify and write them using the EARS patterns. If necessary, elicit other requirements that are not in the text but that should be present.

More warm up exercises with EARS

Ex. 8.4: Another scenario that you've seen in the classes

Lets consider a vending machine with 2 products, apples and bananas, costing 1€ and 2€ respectively. Its users have only 1€ and 2€ coins to interact with the machine. Now, write using EARS patterns the following requirements:

- The user must be able to get apples and bananas;
- The machine accepts up to 3€, and not more than that;
- The machine must give change back when applicable;
- The machine can be powered off and powered on;

Now, a more complex scenario

The problem

I would like the vending machine to sell 3 items: apples, bananas, and chocolates. It should be possible to buy chocolates for 2€ and fruit for 1€. Only 1€ and 2€ coins are accepted. The machine has a maximum capacity for 1€ coins and for 2€ coins. The machine does not accept coins if its capacity is full. The machine should give change back when buying fruit after inserting 2€. If the machine has already 2€ inserted, it refuses another coin. If the machine has no 1€ coins, it cannot sell fruit with a 2€ coin. The user can request the money back after inserting coins.

Ex. 8.5: Identify requirements

Proceed with identifying requirements, classifying and writing them following the EARS patterns.

More system verification?

Syllabus

- Introduction to model-checking
- CCS: a simple language for concurrency
 - Syntax
 - Semantics
 - Equivalence
 - mCRL2: modelling
- Dynamic logic
 - Syntax
 - Semantics
 - Relation with equivalence
 - mCRL2: verification
- Timed Automata
 - Syntax
 - Semantics (composition, Zeno)
 - Equivalence
 - UPPAAL: modelling
- Temporal logics (LTL/CTL)
 - Syntax
 - Semantics
 - UPPAAL: verification
- Probabilistic and stochastic systems
 - Going probabilistic
 - UPPAAL: monte-carlo
- EARS approach

More directions

- Timed processes (+ logic extension)

```
act hit;  
proc Hammer(t:Real) = hit@(t+1).Hammer(t+1);  
init Hammer(0);
```

- Hybrid Automata
 - Lince tool
 - <https://jose.proenca.org/publication/fmas-lince-2024/>
- Verifying families of timed automata
 - Uppex tool
 - <https://jose.proenca.org/publication/proenca-verification-2022/>
 - <https://jose.proenca.org/publication/proenca-spreadsheet-2023/>
- Checking communication protocols with mCRL2
 - Team Automata – avoiding getting stuck
 - <https://jose.proenca.org/publication/terbeek-dlogic-2023/>