Softwaretechnik / Software-Engineering

Lecture 05: Requirements Engineering

2015-05-11

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**Course Content (Original Plan)**

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**Contents & Goals**

**Last Lecture:**
- process models: V-Modell XT, agile (XP, Scrum); process metrics: CMMI, SPICE

**This Lecture:**
- **Educational Objectives:** Capabilities for following tasks/questions.
  - What is requirements engineering (RE)?
  - Why is it important, why is it hard?
  - What are the two (three) most relevant artefacts produced by RE activities?
  - What is a dictionary?
  - What are desired properties of requirements specification (documents)?
  - What are hard/soft/open/tacit/functional/non-functional requirements?
  - What is requirements elicitation?
  - Which analysis technique would you recommend in which situation?

- **Content:**
  - motivation and vocabulary of requirements engineering,
  - the documents of requirements analysis, and desired properties of RE,
  - guidelines for requirements specification using natural language
The hardest single part of building a software system is deciding precisely what to build. No other part of the conceptual work is as difficult as establishing the detailed technical requirements ... No other part of the work so cripples the resulting system if done wrong. No other part is as difficult to rectify later.

F.P. Brooks (Brooks, 1995)
**Requirements and Requirements Analysis**

**requirement** – (1) A condition or capability needed by a user to solve a problem or achieve an objective.
(2) A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed documents.
(3) A documented representation of a condition or capability as in (1) or (2).

*IEEE 610.12 (1990)*

**requirements analysis** – (1) The process of studying user needs to arrive at a definition of system, hardware, or software requirements.
(2) The process of studying and refining system, hardware, or software requirements.

*IEEE 610.12 (1990)*

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**The Requirements Engineering Problem**

- **Requirements engineering**: Describe/specify the set of the allowed computation paths.

- **Software development**: Create one software $S$ whose computation paths $\llbracket S \rrbracket$ are all allowed.
  - **Note**: different programs in different programming languages may also describe $\llbracket S \rrbracket$.
  - **Often allowed**: any refinement of $\rightarrow$ later; e.g. allow intermediate transitions.
Purposes of the Requirements Specification

- **coordination** with the customer (or the marketing department, or ...)
  - not properly clarified/specified requirements are hard to satisfy — mismatches with customer’s needs turn out in operation the latest → additional effort

- **design and implementation**, 
  - programmers may use different interpretations of unclear requirements → difficult integration 

- the user’s **manual**, 
  - if the user’s manual author is not developer, he/she can only describe what the system does, not what it should do (“no more bugs, every observation is a feature”)

- preparation of **tests**, 
  - without a description of allowed outcomes, tests are randomly searching for generic errors (like crashes) → systematic testing impossible 

- **acceptance** by customer, **resolving** later objections or regress claims, 
  - at delivery time unclear whether behaviour is an error (developer needs to fix) or correct (customer needs to accept and pay) → nasty disputes, additional effort

- **re-use**, 
  - re-use based on re-reading the code → risk of unexpected changes 

- later **re-implementations**, 
  - the new software may need to adhere to requirements of the old software; if not properly specified, the new software needs to be a 1:1 re-implementation of the old → additional effort

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the **documentation** of the requirements defines acceptance criteria, 
thus will be considered in any dispute at software delivery time!  
(plus, speaking of documentation, mind the → bus-factor)

actively discussed in industry these days: **traceability**
Once Again: The Software Peoples’ View on Requirements

**Example:** children’s birthday present requirements (birthday on May, 27th).

- “Ich will’n **Pony**!” (“I want a **pony**!”)

- **Common sense understanding:**

  ![Image of horse](http://pixabay.com/en/pony-horse-animal-ride-pasture-368975/) — CC0 Public Domain

  ![Image of Mustang](http://pixabay.com/en/Ford-Mustang-automobile-roof-top-907346/) — CC BY 2.0

  That is: we’re looking for one small horse-like animal; we may (guided by economic concerns, taste, etc.) choose exact breed, size, color, shape, gender, age (may not even be born today, only needs to be alive on birthday)...

- **Software Engineering understanding:**

  We may give **everything** as long as there's a **pony** in it:

  - a herd of ponies,
  - a whole zoo (if it has a pony),
  - ...

  ![Image of Mustang](http://pixabay.com/en/Ford-Mustang-automobile-roof-top-907346/) — CC BY 2.0
In other words:

- **common sense understanding**: choose from \( \emptyset \cup \text{requirements} \)
- **software engineering understanding**: choose from \( \text{chaos} \cap \text{requirements} \)

- \( \mathcal{S} = \{ x \text{ is always } 0 \} \) is a (semi-informal) **software specification**.
- It denotes **all imaginable softwares** with an \( x \) which is always 0:
  \[
  [\mathcal{S}] = \{ S \mid \forall \sigma_0 \xrightarrow{\alpha_1} \sigma_1 \xrightarrow{\alpha_2} \cdots \in [S] \forall i \in \mathbb{N}_0 \cdot \sigma_i \cdot x = 0 \}
  \]
- The software specification “true” (“I don’t care at all”) denotes **chaos**.
- Writing a requirements specification means **constraining chaos**, or describing (a) subset(s) of chaos.
- **Design/Implementation** means: choosing from the obtained subset(s) of chaos.

And What’s Hard About That?

**Example**: customer says “I need a computation of square numbers, i.e. \( f : x \mapsto x^2 \)”

- **We’ve got options** to choose from:

  ```
  1 int sq( int x ) {
    2      return x * x;
  3  }
  ```

  \( \rightarrow 1h, 100 \)€

  with errors: \( sq(2^{31} - 1) = 1 \)

  ```
  1 unsigned int
  2 sq( unsigned short x ) {
  3      return x * x;
  4  }
  ```

  \( \rightarrow 2h, 200 \)€

  not defined for \( 2^{16} \)

  ```
  1 \#include <gmp.h>
  2 void sq( mpz_t x ) {
  3      mpz_mul( x , x , x ) ;
  4  }
  ```

  \( \rightarrow 4h, 400 \)€

  usage non-trivial:

  ```
  1 mpz_t x ;
  2 mpz_init(x) ;
  3 mpz_set_ui( x, 2147483647 ) ;
  4 sq(x) ;
  5 fprintf( stdout, "%lu\n", 2147483647 ) ;
  6 mpz_clear( stdout , 10 , x ) ;
  7 fprintf( stdout, "\a\" ) ;
  ```

- Okay, **customer said**: input values are from \( \{0, \ldots , 27\} \).
- **Still**, we’ve got options… :

  ```
  1 unsigned int sq( unsigned short x ) {
  2      unsigned int r = 0 , n ;
  3      for ( n = x ; n ; --n ) {
  4          r += x ; sleep(1) ;
  5      }
  6      return r ;
  7  }
  ```
A First Summary

A good requirements specification
(i) avoids disputes with the customer at (milestones or) delivery time,
(ii) prevents us from doing too little/too much work,
(iii) is economic (see below).

There’s a tradeoff between narrowness and openness:
• the optimum wrt. (i) and (ii) is the complete, perfect software product as needed by the customer (most narrow):
  • no disputes; amount of work needed is clear.
  Drawback: hard/expensive to get, that’s bad for (iii).
• The cheapest (not: most economic) requirements specification is “do what you want” (most open).
  Drawback: high risk value for not doing (i) and (ii).
• Being too narrow has another severe drawback...

... Namely: Requirements Specification vs. Design

• Idealised views advocate a strict separation between requirements (“what is to be done?”) and design (“how are things done?”).
• Rationale: Fixing too much of the “how” too early may unnecessarily narrow down the design space and inhibit new ideas.

There may be better (easier, cheaper, ...) solutions than the one imagined first.

• In practice, this separation is often neither possible nor advisable:
  • Existing components should be considered. (→ re-use)
  • Customer, (safety) regulations, norms, etc. may require a particular solution anyway.
  • It is often useful to reflect real-world structures in the software.
  • In some (low risk) cases it may be more economical to skip requirements analysis and directly code (and document!) a proposal.
  • Complex systems may need a preliminary system design before being able to understand and describe requirements.
  • One way to check a requirements specification for consistency (realisability) is to think through at least one possible solution.
  • The requirements specification should answer questions arising during development.
Requirements Analysis Basics

• **Note**: analysis in the sense of "finding out what the exact requirements are". "Analysing an existing requirements/feature specification" → later.

In the following we shall discuss:

(i) **documents** of the requirements analysis:
   - dictionary,
   - requirements/feature specification.

(ii) **desired properties** of
   - requirements specifications,
   - requirements specification documents,

(iii) **kinds** of requirements
   - hard and soft,
   - open and tacit,
   - functional and non-functional, •sigh•

(iv) (a selection of) **analysis techniques**
Requirements analysis should be based on a **dictionary**.

A **dictionary** comprises definitions and clarifications of **terms** that are relevant to the project and of which different people (in particular customer and developer) may have different understandings before agreeing on the dictionary.

Each entry in the dictionary should provide the following information:

- **term** and **synonyms** (in the sense of the requirements specification),
- **meaning** (definition, explanation),
- **delimitations** (where not to use this terms),
- **validness** (in time, in space, ...),
- **denotation**, unique identifiers, ...,
- **open questions** not yet resolved,
- **related terms**, cross references.

**Note**: entries for terms that seem “crystal clear” at first sight are not uncommon.

All work on requirements should, as far as possible, be done using terms from the dictionary consistently and consequently.

The dictionary should in particular be negotiated with the customer and used in communication (if not possible, at least developers should stick to dictionary terms).

**Note**: do not mix up real-world/domain terms with ones only “living” in the software.

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**Dictionary Example (With Room for Improvement)**

**Example**: **Wireless Fire Alarm System**

- During a project on designing a highly reliable, EN-54-25 conforming wireless communication protocol, we had to learn that the relevant components of a fire alarm system are
  - **terminal participants** (wireless sensors and manual indicators),
  - **a central unit** (not a participant),
  - and **repeaters** (a non-terminal participant).
- Repeaters and central unit are technically very similar, but need to be distinguished to understand requirements. The dictionary explains these terms.

(Arenis et al., 2014)
Example: Wireless Fire Alarm System

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Excerpt from the dictionary (ca. 50 entries):

Part
A part of a fire alarm system is either a participant or a central unit.

Repeater
A repeater is a participant which accepts messages for the central unit from other participants, or messages from the central unit to other participants. A repeater consists of the following devices: wireless communication module (1 to 4, here fixed to 2), [...] Central Unit
A central unit is a part which receives messages from different assigned participants, assesses the messages, and reacts, e.g. by forwarding to persons or optical/acoustic signalling devices. A central unit consist of the following devices: [...] Terminal Participant
A terminal participant is a participant which is not a repeater. Each terminal participant consists of exactly one wireless communication module and devices which provide sensor and/or signalling functionality.

Documents of the Requirements Analysis: Specifications

- Recall:
  Lastenheft (Requirements Specification) Entire demands on deliverables and services of a developer within a contracted development, created by the customer.
  Pflichtenheft (Feature Specification) Specification of how to realise a given requirements specification, created by the developer.

- Recommendation:
  If the requirements specification is not given by customer (but needs to be developed), focus on and maintain only the collection of requirements (possibly sketchy and unsorted) and maintain the feature specification.

  (Ludewig and Lichter, 2013)

- Note: In the following (unless otherwise noted), we discuss the feature specification, i.e. the basis of the software development.
  To maximise confusion, we may occasionally (inconsistently) call it requirements specification or just specification — should be clear from context...
Requirements on Requirements Specifications

A requirements specification should be

- **correct**
  - it correctly represents the wishes/needs of the customer,

- **complete**
  - all requirements (existing in somebody’s head, or a document, or . . . ) should be present,

- **relevant**
  - things which are not relevant to the project should not be constrained,

- **consistent, free of contradictions**
  - each requirement is compatible with all other requirements; otherwise the requirements are not realisable,

- **neutral, abstract**
  - a requirements specification does not constrain the realisation more than necessary,

- **traceable, comprehensible**
  - the sources of requirements are documented, requirements are uniquely identifiable,

- **testable, objective**
  - the final product can objectively be checked for satisfying a requirement.

The Crux of Requirements Engineering

- **Correctness** and **completeness** of a requirements specification is defined relative to something which is usually only in the customer’s head.
  - → in that case, there is hardly a chance to be sure of correctness and completeness.

- “Dear customer, please tell me/write down what is in your head!”
  - is in almost all cases not a solution!

- It’s not unusual that even the customer does not precisely know . . . !
  - For example, the customer may not be aware of contradictions due to technical limitations.
The representation and form of a requirements specification should be:

- **easily understandable, not unnecessarily complicated** —
  all affected people are able to understand the requirements specification,

- **precise** —
  the requirements specification does not introduce new unclarities or rooms for interpretation (→ testable, objective),

- **easily maintainable** —
  creating and maintaining the requirements specification should be easy and should not need unnecessary effort,

- **easily usable** —
  storage of and access to the requirements specification should not need significant effort.

**Note:** Once again, it’s about compromises.

- A very precise **objective** requirements specification may not be easily understandable by every affected person.
  → provide redundant explanations.

- It is not easy to have both, low maintenance effort and low access effort.
  → value low access effort higher, a requirements specification document is much more often read than changed or written (most changes require reading beforehand).

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**Kinds of Requirements**
Kinds of Requirements: Hard and Soft Requirements

- **Example of a hard requirement:**
  - Cashing a cheque over \( N \) € must result in a new balance decreased by \( N \); there is not a micro-cent of tolerance.

- **Examples of soft requirements:**
  - If the vending machine dispenses the selected item within 1 s, it’s clearly fine; if it takes 5 min., it’s clearly wrong — where’s the boundary?
  - A car entertainment system which produces “noise” (due to limited bus bandwidth or CPU power) in average once per hour is acceptable, once per minute is not acceptable.

The border between hard/soft is difficult to draw:

- As **developer**, we want requirements specifications to be “as hard as possible”, i.e. we want a clear right/wrong.
- As **customer**, we often cannot provide this clarity; we know what is “clearly wrong” and we know what is “clearly right”, but we don’t have a sharp boundary.

→ intervals, rates, etc. can serve as precise specifications of soft requirements.

Kinds of Requirements: Open and Tacit

- **open**: customer is aware of and able to explicitly communicate the requirement,
- **(semi-)tacit**: customer not aware of something being a requirement (obvious to the customer, not considered relevant by the customer, not known to be relevant).

**Examples:**

- buttons and screen of a mobile phone should be on the same side,
- important web-shop items should be on the right side because our main users are socialised with right-to-left reading direction,
- the ECU (embedded control unit) may only use a certain amount of bus capacity.
- distinguish **don’t care**: intentionally left to be decided by developer.

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**Analyst**

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<td>requirements discoverable with difficulties</td>
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**Customer/Client**

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<td></td>
<td>requirements discovered</td>
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</table>

(Gacitua et al., 2009)
Kinds of Requirements: Functional and Non-Functional

- *sigh*

- Recall definition of software:

  A finite description of a set of computation paths of the form

  \[ \pi = \sigma_0 \xrightarrow{\alpha_1} \sigma_1 \xrightarrow{\alpha_2} \sigma_2 \cdots \]

  Note: states \( \sigma \) may be labelled with timestamps, or energy consumption so far, …

- Another view: software is a function which maps input to output sequences:

  \[ S: \sigma^i_0 \xrightarrow{\alpha^i_1} \sigma^i_1 \xrightarrow{\alpha^i_2} \sigma^i_2 \cdots \xrightarrow{} (\sigma^o_0 \sigma^o_1 \sigma^o_2 \cdots) \]

- Every constraint on things observable in the computation paths is a functional requirement (because it requires something for the function \( S \)).

  Thus timing, energy consumption, etc. may be subject to functional requirements.

- Clearly non-functional requirements:

  programming language, coding conventions, process model requirements, portability…

Requirements Analysis Techniques
(A Selection of) Analysis Techniques

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<td>Participative development</td>
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(Ludewig and Lichter, 2013)

Requirements Elicitation

- **Observation:**
  Customers are typically not trained in stating/communicating requirements. They live in the "I want a pony"-world — in multiple senses... ;)

- It is the task of the analyst to:
  - ask what is wanted,
  - ask what is not wanted,
  - establish precision, look out for contradictions,
  - anticipate exceptions, difficulties, corner-cases,
  - have technical background to know technical difficulties,
  - communicate (formal) specification to customer,
  - "test" own understanding by asking more questions.

→ i.e. to elicit the requirements.

A made up dialogue:

**Analyst:** So in the morning, you open the door at the main entrance?
**Customer:** Yes, as I told you.
**A:** Every morning?
**C:** Of course.
**A:** Also on the weekends?
**C:** No, on weekends, the entrance stays closed.
**A:** And during company holidays?
**C:** Then it also remains closed of course.
**A:** And if you are ill or on vacation?
**C:** Then Mr. M opens the door.
**A:** And if Mr. M is not available, too?
**C:** Then the first client will knock on the window.
**A:** Okay. Now what exactly does "morning" mean?

... (Ludewig and Lichter, 2013)
How Can Requirements Engineering Look In Practice?

- Set up a core team for analysis (3 to 4 people), include experts from the domain and developers. Analysis benefits from highest skills and strong experience.

- During analysis, talk to decision makers (managers), domain experts, and users. Users can be interviewed by a team of 2 analysts, ca. 90 min.

- The resulting “raw material” is sorted and assessed in half- or full-day workshops in a team of 6-10 people. One searches for, e.g., contradictions between customer wishes, and for prioritisation.

  Note: The customer decides. Analysts may make proposals (different options to choose from), but the customer chooses. (And the choice is documented.)

- The “raw material” is basis of a preliminary requirements specification (audience: the developers) with open questions.

  Analysts need to communicate the requirements specification appropriately (explain, give examples, point out particular corner-cases). Customers without strong maths/computer science background are often overstrained when “left alone” with a formal requirements specification.

- Result: dictionary, specified requirements.

  - Many customers do not want (radical) change, but improvement.
  - Good questions: How’re things done today? What should be improved?

Specification Languages
**Requirements Specification Language**

**specification** — A document that specifies, in a complete, precise, verifiable manner, the requirements, design, behavior, or other characteristics of a system or component, and, often, the procedures for determining whether these provisions have been satisfied.  

IEEE 610.12 (1990)

**specification language** — A language, often a machine-processible combination of natural and formal language, used to express the requirements, design, behavior, or other characteristics of a system or component. For example, a design language or requirements specification language. Contrast with: programming language; query language.  

IEEE 610.12 (1990)

**requirements specification language** — A specification language with special constructs and, sometimes, verification protocols, used to develop, analyze, and document hardware or software requirements.  

IEEE 610.12 (1990)

**software requirements specification (SRS)** — Documentation of the essential requirements (functions, performance, design constraints, and attributes) of the software and its external interfaces.  

IEEE 610.12 (1990)

**Natural Language Specification**

(Ludewig and Lichter, 2013) based on (Rupp and die SOPHISTen, 2009):

<table>
<thead>
<tr>
<th>rule</th>
<th>explanation, example</th>
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<tbody>
<tr>
<td>R1</td>
<td>State each requirement in active voice.</td>
</tr>
<tr>
<td>R2</td>
<td>Express processes by full verbs.</td>
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<tr>
<td>R3</td>
<td>Discover incompletely defined verbs.</td>
</tr>
<tr>
<td>R4</td>
<td>Discover incomplete conditions.</td>
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<tr>
<td>R5</td>
<td>Discover universal quantifiers.</td>
</tr>
<tr>
<td>R6</td>
<td>Check nouns like “registration” often hide complex processes.</td>
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<tr>
<td>R6</td>
<td>Check nominalisations.</td>
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<tr>
<td>R7</td>
<td>Recognise and refine unclear substantives.</td>
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<tr>
<td>R8</td>
<td>Clarify responsibilities.</td>
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<tr>
<td>R9</td>
<td>Identify implicit assumptions.</td>
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</tbody>
</table>

**Natural Language Patterns**

Natural language requirements can be written using $A$, $B$, $C$, $D$, $E$, $F$ where

- **$A$** clarifies when and under what conditions the activity takes place
- **$B$** is MUST (obligation), SHOULD (wish), or WILL (intention); also: MUST NOT (forbidden)
- **$C$** is either “the system” or the concrete name of a (sub-)system
- **$D$** one of three possibilities:
  - “does”, description of a system activity,
  - “offers”, description of a function offered by the system to somebody,
  - “is able if”, usage of a function offered by a third party, under certain conditions
- **$E$** extensions, in particular an object
- **$F$** the actual process word (what happens)

*(Rupp and die SOPHISTen, 2009)*

**Example:**

After office hours ($= A$), the system ($= C$) should ($= B$) offer to the operator ($= D$) a backup ($= F$) of all new registrations to an external medium ($= E$).
Other Pattern Example: RFC 2119

RFC 2119                     RFC Key Words                    March 1997

5. MAY  This word, or the adjective "OPTIONAL", mean that truly optional. One would say "MAY" to include the option if a particular marketplace requires it or because the vendor feels it enhances the product while another vendor may omit it because it does not fit in an implementation which does not include a particular option. An implementation which does not include an option that is "MAY" be prepared to interoperate with another implementation which includes the option, though perhaps with reduced function name or an implementation which does not include the option (except, of course, for the option provided.)

6. Guidance in the use of these Imperatives

Imperson may use these Imperatives when the type defined in this memo are to be interpreted as described in IETF documents. Authors who follow these guidelines may use the key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119.

Note that the force of these words is modified by the requirement level of the document in which they are used.

1. MUST  This word, or the term "REQUIRED" mean that the definition is an absolute requirement of the specification. It is essentially a condition of conformance and implies that no functional aspects of the specification may be ignored. If a protocol or product is conformed to a standard which includes the word "MUST", then it is required to implement all requirements defined as "MUST". In other words, if a protocol or product is conformed to a standard which includes the word "MUST", then it is required to implement all requirements defined as "MUST". The word "MUST" implies that the implementation is required to ensure interoperability. An implementation which does not include a particular option MUST be prepared to interoperate with another implementation which includes the option, though perhaps with reduced function name or an implementation which does not include the option. An implementation which does not include an option that is "MUST" be prepared to interoperate with another implementation which includes the option, though perhaps with reduced function name or an implementation which does not include the option (except, of course, for the option provided.)

2. MUST NOT  This phrase, or the phrase "SHALL NOT", mean that the definition is an absolute prohibition of the specification. The word "MUST NOT" implies that the implementation must not include the option or use a particular method or parameter. If a protocol or product is conformed to a standard which includes the word "MUST NOT", then it is not allowed to implement any functionality that is an absolute method or parameter. The word "MUST NOT" implies that the implementation is required to ensure interoperability. An implementation which includes a particular option MUST be prepared to interoperate with another implementation which does not include the option, though perhaps with reduced function name or an implementation which does not include the option. An implementation which includes an option that is "MUST NOT" be prepared to interoperate with another implementation which includes the option, though perhaps with reduced function name or an implementation which does not include the option (except, of course, for the option provided.)

3. SHOULD  This word, or the adjective "RECOMMENDED", mean that there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and the case carefully weighed before implementing any behavior described with this label.

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(Ludewig and Lichter, 2013) based on (IEEE, 1998)