UNIT-II: SOFTWARE REQUIREMENTS ANALYSIS AND MODELLING

a. REQUIREMENT ENGINEERING

Understanding the requirements of a problem is among the most difficult tasks that face a software engineer. When you first think about it, developing a clear understanding of requirements doesn't seem that hard. After all, doesn't the customer know what is required? Shouldn't the end users have a good understanding of the features and functions that will provide benefit? Surprisingly, in many instances the answer to these questions is "no." And even if customers and end-users are explicit in their needs, those needs will change throughout the project.

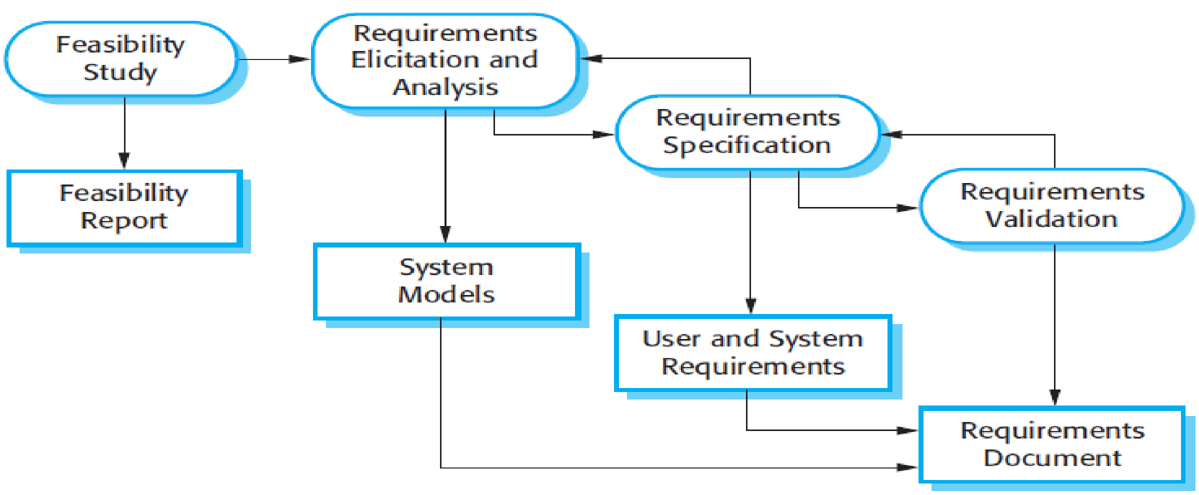
- The requirements for a system are the descriptions of what the system should do— the services that it provides and the constraints on its operation. These requirements reflect the needs of customers for a system that serves a certain purpose such as controlling a device, placing an order, or finding information. The process of finding out, analyzing, documenting and checking these services and constraints is called requirements engineering (RE).
- **Requirement engineering establishes a solid base for design and construction. Without it, the resulting software has a high probability of not meeting customer's needs.**
- Requirement engineering provides the appropriate mechanism for understanding what the customer wants, analyzing need, assessing feasibility, negotiating a reasonable solution, specifying the solution unambiguously, validating the specification, and managing the requirements as they are transformed into an operational system. It encompasses ***seven distinct tasks***: **inception, elicitation, elaboration, negotiation, specification, validation, and management**. It is important to note that some of these tasks occur in parallel and all are adapted to the needs of the project.
- **Inception** :- How does a software project get started? Is there a single event that becomes the catalyst for a new computer-based system or product, or does the need evolve over time?
  - At project inception, you establish a basic understanding of the problem, the people who want a solution, the nature of the solution that is desired, and the effectiveness of preliminary communication and collaboration between the other stakeholders and the software team.
  - *Problems of scope*- The boundary of the system is ill-defined or the customers/users specify unnecessary technical detail that may confuse, rather than clarify, overall system objectives
  - *Problems of understanding*- The customers/users are not completely sure of what is needed, have a poor understanding of the capabilities and limitations of their computing environment, don't have a full understanding of the problem domain, have trouble communicating needs to the system engineer, omit information that is believed to be "obvious," specify requirements that conflict with the needs of other customers/users, or specify requirements that are ambiguous or untestable.
  - *Problems of volatility*- The requirements change over time.
- **Elaboration**:- The information obtained from the customer during inception and elicitation is expanded and refined during elaboration. This task focuses on developing a refined requirements model that identifies various aspects of software function, behavior, and information. Elaboration is driven by the creation and refinement of user scenarios that describe how the end user (and other actors) will interact with the system. Each user scenario is parsed to extract analysis classes—business domain entities that are visible to the end

user. The attributes of each analysis class are defined, and the services that are required by each class are identified. The relationships and collaboration between classes are identified, and a variety of supplementary diagrams are produced

- **Negotiation**: -Customers, users, and other stakeholders are asked to rank requirements and then discuss conflicts in priority. Using an iterative approach that prioritizes requirements, assesses their cost and risk, and addresses internal conflicts, requirements are eliminated, combined, and/or modified so that each party achieves some measure of satisfaction.
- **Specification**: -In the context of computer-based systems (and software), the term specification means different things to different people. A specification can be a written document, a set of graphical models, a formal mathematical model, a collection of usage scenarios, a prototype, or any combination of these**. The formality and format of a specification varies with the size and the complexity of the software to be built.**
- **Validation:-** The work products produced as a consequence of requirements engineering are assessed for quality during a validation step.
- **Requirements management:-**Requirements management is a set of activities that help the project team identify, control, and track requirements and changes to requirements at any time as the project proceeds.

Elicitation:- It certainly seems simple enough—ask the customer, the users, and others what the objectives for the system or product are, what is to be accomplished, how the system or product fits into the needs of the business, and finally, how the system or product is to be used on a day-to-day basis. But it isn't simple—it's very hard.

ACTIVITIES IN REQUIREMENT ENGINEERING



- **Types of Feasibility:**

1. **Technical Feasibility -** Technical feasibility evaluates the current technologies, which are needed to accomplish customer requirements within the time and budget.
2. **Operational Feasibility -** Operational feasibility assesses the range in which the required software performs a series of levels to solve business problems and customer requirements.

3. **Economic Feasibility -** Economic feasibility decides whether the necessary software can generate financial profits for an organization.

Requirement Elicitation and Analysis:

- This is also known as the **gathering of requirements**. Here, requirements are identified with the help of customers and existing systems processes, if available.
- Analysis of requirements starts with requirement elicitation. The requirements are analyzed to identify inconsistencies, defects, omission, etc. We describe requirements in terms of relationships and also resolve conflicts if any.

Problems of Elicitation and Analysis

- Getting all, and only, the right people involved.
- Stakeholders often don't know what they want
- Stakeholders' express requirements in their terms.
- Stakeholders may have conflicting requirements.
- Requirement change during the analysis process.
- Software Requirement Specification:
- Software requirement specification is a kind of document which is created by a software analyst after the requirements collected from the various sources - the requirement received by the customer written in ordinary language. It is the job of the analyst to write the requirement in technical language so that they can be understood and beneficial by the development team.
- The models used at this stage include ER diagrams, data flow diagrams (DFDs), function decomposition diagrams (FDDs), data dictionaries, etc.

Software Requirement Validation: After requirement specifications developed, the requirements discussed in this document are validated. The user might demand illegal, impossible solution or experts may misinterpret the needs. Requirements can be the check against the following conditions -

- If they can practically implement
- If they are correct and as per the functionality and specially of software
- If there are any ambiguities
- If they are full
- If they can describe

Requirements Validation Techniques

- **Requirements reviews/inspections:** systematic manual analysis of the requirements.
- **Prototyping:** Using an executable model of the system to check requirements.
- **Test-case generation:** Developing tests for requirements to check testability.
- **Automated consistency analysis:** checking for the consistency of structured requirements descriptions.

TYPES OF REQUIREMENTS

1. **Functional requirements** :- these are statements of services the system should provide, how the system should react to particular inputs, and how the system should behave in particular situations. In some cases, the functional requirements may also explicitly state what the system should not do.
2. **Non-functional requirements** :- these are constraints on the services or functions offered by the system. They include timing constraints, constraints on the development process, and constraints imposed by standards. Non-functional requirements often apply to the system as a whole, rather than individual system features or services.

FUNCTIONAL REQUIREMENTS:

- The functional requirements for a system describe what the system should do. These requirements depend on the type of software being developed, the expected users of the software, and the general approach taken by the organization when writing requirements. When expressed as user requirements, functional requirements are usually described in an abstract way that can be understood by system users. However, more specific functional system requirements describe the system functions, its inputs and outputs, exceptions, etc., in detail.

NONFUNCTIONAL REQUIREMENTS:

- Non-functional requirements, as the name suggests, are requirements that are not directly concerned with the specific services delivered by the system to its users. They may relate to emergent system properties such as reliability, response time, and store occupancy.
- Non-functional requirements, such as performance, security, or availability, usually specify or constrain characteristics of the system as a whole.
- A **functional requirement** specifies something that the application or system should do. Often, this is defined as a behavior of the system that takes input and provides output. For example, a traveler fills out a form in an airline's mobile application with his/her name and passport details (input), submits the form, and the application generates a boarding pass with the traveler's details (output).
- **Non-functional requirements**, sometimes also called quality requirements, describe how the system should be, as opposed to what it should do. Non-functional requirements of a system include performance (e.g., response time), maintainability and scalability, among many others. In the airline application example, the requirement that the application must display the boarding pass after a maximum of five seconds from the time the traveler presses the 'submit' button would be a non-functional requirement.

b. ESTABLISHING THE GROUNDWORK

In an ideal setting, stakeholders and software engineers work together on the same team.8 In such cases, requirements engineering is simply a matter of conducting meaningful conversations with colleagues who are well-known members of the team. But reality is often quite different.

Customer(s) or end users may be located in a different city or country, may have only a vague idea of what is required, may have conflicting opinions about the system to be built, may have limited technical knowledge, and may have limited time to interact with the requirements engineer. None of these things are desirable, but all are fairly common, and you are often forced to work within the constraints imposed by this situation

Identifying Stakeholders: **-A stakeholder is anyone who has a direct interest in or benefits from the system that is to be developed**.

Stakeholder can be the following: -business operations managers, product managers, marketing people, internal and external customers, end users, consultants, product engineers, software engineers, support and maintenance engineers, and others. Each stakeholder has a different view of the system, achieves different benefits when the system is successfully developed, and is open to different risks if the development effort should fail.

- **Recognizing Multiple Viewpoints**
  - “Put three stakeholders in a room and ask them what kind of system they want. You’re likely to get four or more different opinions.” Author unknown
  - Because many different stakeholders exist, the requirements of the system will be explored from many different points of view. For example, the marketing group is in   terested in functions and features that will excite the potential market, making the new system easy to sell. Business managers are interested in a feature set that can be built within budget and that will be ready to meet defined market windows. End users may want features that are familiar to them and that are easy to learn and use. Software engineers may be concerned with functions that are invisible to nontechnical stakeholders but that enable an infrastructure that supports more marketable functions and features. Support engineers may focus on the maintainability of the software.

- You should categorize all stakeholder information (including inconsistent and conflicting requirements) in a way that will allow decision makers to choose an internally consistent set of requirements for the system.

- **Working toward Collaboration**
  - The job of a requirements engineer is to identify areas of commonality (i.e., re quirements on which all stakeholders agree) and areas of conflict or inconsistency (i.e., requirements that are desired by one stakeholder but conflict with the needs of another stakeholder). It is, of course, the latter category that presents a challenge.
  - Collaboration does not necessarily mean that requirements are defined by committee. In many cases, stakeholders collaborate by providing their view of requirements, but a strong "project champion"(e.g., a business manager or a senior technologist) may make the final decision about which requirements make the cut.

Asking the First Questions

- Questions asked at the inception of the project should be "context free" .The first set of context-free questions focuses on the customer and other stakeholders, the overall project goals and benefits.
- For example, you might ask:

  • Who is behind the request for this work?

  • Who will use the solution?

  • What will be the economic benefit of a successful solution?

  • Is there another source for the solution that you need?

c. ELICITING REQUIREMENTS

Requirement's elicitation (also called *requirements gathering*) combines elements of problem solving, elaboration, negotiation, and specification. In order to encourage a collaborative, team-oriented approach to requirements gathering, stakeholders work together to identify the problem, propose elements of the solution, negotiate different approaches and specify a preliminary set of solution requirements.

➢ Collaborative Requirements Gathering

Many different approaches to collaborative requirements gathering have been proposed. Each makes use of a slightly different scenario, but all apply some variation on the following basic guidelines:

- Meetings are conducted and attended by both software engineers and other stakeholders.
- Rules for preparation and participation are established.
- An agenda is suggested that is formal enough to cover all important points but informal enough to encourage the free flow of ideas.
- A "facilitator" (can be a customer, a developer, or an outsider) controls the meeting.
- A "definition mechanism" (can be work sheets, flip charts, or wall stickers or an electronic bulletin board, chat room, or virtual forum) is used.

During inception basic questions and answers establish the scope of the problem and the overall perception of a solution. Out of these initial meetings, the developer and customers write a one- or two-page "product request."

A meeting place, time, and date are selected; a facilitator is chosen; and attendees from the software team and other stakeholder organizations are invited to participate. The product request is distributed to all attendees before the meeting date.

As an example, consider an excerpt from a product request written by a marketing person involved in the *SafeHome* project. This person writes the following narrative about the home security function that is to be part of *SafeHome:*

Our research indicates that the market for home management systems is growing at a rate of 40 percent per year. The first *SafeHome* function we bring to market should be the home security function. Most people are familiar with "alarm systems" so this would be an easy sell.

> The home security function would protect against and/or recognize a variety of undesirable "situations" such as illegal entry, fire, flooding, carbon monoxide levels, and others. It'll use our wireless sensors to detect each situation. It can be programmed by the homeowner, and will automatically telephone a monitoring agency when a situation is detected.

While reviewing the product request in the days before the meeting, each attendee is asked to make a list of objects that are part of the environment that surrounds the system, other objects that are to be produced by the system, and objects that are used by the system to perform its functions. In addition, each attendee is asked to make another list of services (processes or functions) that manipulate or interact with the objects. Finally, lists of constraints (e.g., cost, size, business rules) and performance criteria (e.g., speed, accuracy) are also developed. The attendees are informed that the lists are not expected to be exhaustive but are expected to reflect each person's perception of the system.

Objects described for *SafeHome* might include the control panel, smoke detectors, window and door sensors, motion detectors, an alarm, an event (a sensor has been activated), a display, a PC, telephone numbers, a telephone call, and so on. The list of services might include *configuring* the system, *setting* the alarm, *monitoring* the sensors, *dialing* the phone, *programming* the control panel, and *reading* the display (note that services act on objects). In a similar fashion, each attendee will develop lists of constraints (e.g., the system must recognize when sensors are not operating, must be user-friendly, must interface directly to a standard phone line) and performance criteria (e.g., a sensor event should be recognized within one second, and an event priority scheme should be implemented).

The lists of objects can be pinned to the walls of the room using large sheets of paper, stuck to the walls using adhesive-backed sheets, or written on a wall board. Alternatively, the lists may have been posted on an electronic bulletin board, at an internal website, or posed in a chat room environment for review prior to the meeting. Ideally, each listed entry should be capable of being manipulated separately so that lists can be combined, entries can be modified, and additions can be made. At this stage, critique and debate are strictly prohibited.

After individual lists are presented in one topic area, the group creates a combined list by eliminating redundant entries, adding any new ideas that come up during the discussion, but not deleting anything. After you create combined lists for all topic areas, discussion—coordinated by the facilitator—ensues. The combined list is shortened, lengthened, or reworded to properly reflect the product/system to be developed.

The objective is to develop a consensus list of objects, services, constraints, and performance for the system to be built.

In many cases, an object or service described on a list will require further explanation. To accomplish this, stakeholders develop *mini-specifications* for entries on the lists. Each mini-specification is an elaboration of an object or service. For example, the mini-spec for the *SafeHome* object

> Control Panel might be: The control panel is a wall-mounted unit that is approximately 9X5 inches in size. The control panel has wireless connectivity to sensors and a PC. User interaction occurs through a keypad containing 12 keys. A 3X3 inch LCD color display provides user feedback. Software provides interactive prompts, echo, and similar functions.

The mini-specs are presented to all stakeholders for discussion. Additions, deletions, and further elaboration are made. In some cases, the development of mini-specs will uncover new objects, services, constraints, or performance requirements that will be added to the original lists. During all discussions, the team may raise an issue that cannot be resolved during the meeting. An *issues list* is maintained so that these ideas will be acted on later.

➢ Quality Function Deployment

Quality function deployment (QFD) is a quality management technique that translates the needs of the customer into technical requirements for software. QFD "concentrates on maximizing customer satisfaction from the software engineering process". To accomplish this, QFD emphasizes an understanding of what is valuable to the customer and then deploys these values throughout the engineering process.

QFD identifies three types of requirements:

Normal requirements. The objectives and goals that are stated for a product or system during meetings with the customer. If these requirements are present, the customer is satisfied. Examples of normal requirements might be requested types of graphical displays, specific system functions, and defined levels of performance.

Expected requirements. These requirements are implicit to the product or system and may be so fundamental that the customer does not explicitly state them. Their absence will be a cause for significant dissatisfaction.

Examples of expected requirements are: ease of human/machine interaction, overall operational correctness and reliability, and ease of software installation.

Exciting requirements. These features go beyond the customer's expectations and prove to be very satisfying when present. For example, software for a new mobile phone comes with standard features, but is coupled with a set of unexpected capabilities (e.g., multi touch screen, visual voice mail) that delight every user of the product.

Although QFD concepts can be applied across the entire software process, specific QFD techniques are applicable to the requirements elicitation activity. QFD uses customer interviews and observation, surveys, and examination of historical data (e.g., problem reports) as raw data for the requirements gathering activity. These data are then translated into a table of requirements—called the *customer voice table*—that is reviewed with the customer and other stakeholders. A variety of diagrams, matrices, and evaluation methods are then used to extract expected requirements and to attempt to derive exciting requirements.

➢ Usage Scenarios

As requirements are gathered, an overall vision of system functions and features begins to materialize. However, it is difficult to move into more technical software engineering activities until you understand how these functions and features will be used by different classes of end users. To accomplish this, developers and users can create a set of scenarios that identify a thread of usage for the system to be constructed.

The scenarios, often called *use cases*, provide a description of how the system will be used.

➢ Elicitation Work Products

The work products produced as a consequence of requirements elicitation will vary depending on the size of the system or product to be built. For most systems, the work products include

- A statement of need and feasibility.
- A bounded statement of scope for the system or product.
- A list of customers, users, and other stakeholders who participated in requirements elicitation.
- A description of the system's technical environment.
- A list of requirements (preferably organized by function) and the domain constraints that apply to each.
- A set of usage scenarios that provide insight into the use of the system or product under different operating conditions.
- Any prototypes developed to better define requirements.

Each of these work products is reviewed by all people who have participated in requirements elicitation.

d. BUILDING THE REQUIREMENTS MODEL

The intent of the analysis model is to provide a description of the required informational, functional, and behavioral domains for a computer-based system. The model changes dynamically as you learn more about the system to be built, and other stakeholders understand more about what they really require. For that *r*eason, the analysis model is a snapshot of requirements at any given time.

➢ Elements of the Requirements Model

A set of generic elements is common to most requirements models.

Scenario-based elements. The system is described from the user's point of view using a scenario-based approach. For example, basic use cases. Scenario-based elements of the requirements model are often the first part of the model that is developed. As such, they serve as input for the creation of other modeling elements.

Class-based elements. Each usage scenario implies a set of objects that are manipulated as an actor interacts with the system. These objects are categorized into classes—a collection of things that have similar attributes and common behaviors. For example, a UML class diagram. In addition to class diagrams, other analysis modeling elements describe the manner in which classes collaborate with one another and the relationships and interactions between classes.

Behavioral elements. The behavior of a computer-based system can have a profound effect on the design that is chosen and the implementation approach that is applied. Therefore, the requirements model must provide modeling elements that describe behavior.

The *state diagram* is one method for representing the behavior of a system by depicting its states and the events that cause the system to change state. A *state* is any externally observable mode of behavior. In addition, the state diagram indicates actions (e.g., process activation) taken as a consequence of a particular event.

Flow-oriented elements. Information is transformed as it flows through a computer-based system. The system accepts input in a variety of forms, applies functions to transform it, and produces output in a variety of forms. Input may be a control signal transmitted by a transducer, a series of numbers typed by a human operator, a packet of information transmitted on a network link, or a voluminous data file retrieved from secondary storage. The transform(s) may comprise a single logical comparison, a complex numerical algorithm, or a rule-inference approach of an expert system. Output may light a single LED or produce a 200-page report. In effect, we can create a flow model for any computer-based system, regardless of size and complexity.

➢ Analysis Patterns

Anyone who has done requirements engineering on more than a few software projects begins to notice that certain problems reoccur across all projects within a specific application domain.These *analysis pattern* suggest solutions (e.g., a class, a function, a behavior) within the application domain that can be reused when modeling many applications.

Geyer-Schulz and Hahsler suggest two benefits that can be associated with the use of analysis patterns:

> First, analysis patterns speed up the development of abstract analysis models that capture the main requirements of the concrete problem by providing reusable analysis models with examples as well as a description of advantages and limitations. Second, analysis patterns facilitate the transformation of the analysis model into a design model by suggesting design patterns and reliable solutions for common problems.

Analysis patterns are integrated into the analysis model by reference to the pattern name. They are also stored in a repository so that requirements engineers can use search facilities to find and apply them. Information about an analysis pattern (and other types of patterns) is presented in a standard template.

e. NEGOTIATING REQUIREMENTS

The intent of this negotiation is to develop a project plan that meets stakeholder needs while at the same time reflecting the real-world constraints (e.g., time, people, budget) that have been placed on the software team.

The best negotiations strive for a “win-win” result. That is, stakeholders win by getting the system or product that satisfies the majority of their needs and you (as a member of the software team) win by working to realistic and achievable budgets and deadlines.

Boehm defines a set of negotiation activities at the beginning of each software process iteration. Rather than a single customer communication activity, the following activities are defined:

1. Identification of the system or subsystem’s key stakeholders.
2. Determination of the stakeholders’ “win conditions.”
3. Negotiation of the stakeholders’ win conditions to reconcile them into a set of win-win conditions for all concerned (including the software team).

Successful completion of these initial steps achieves a win-win result, which becomes the key criterion for proceeding to subsequent software engineering activities.

f. VALIDATING REQUIREMENTS

As each element of the requirements model is created, it is examined for inconsistency, omissions, and ambiguity. The requirements represented by the model are prioritized by the stakeholders and grouped within requirements packages that will be implemented as software increments. A review of the requirements model addresses the following questions:

- Is each requirement consistent with the overall objectives for the system/product?
- Have all requirements been specified at the proper level of abstraction? That is, do some requirements provide a level of technical detail that is inappropriate at this stage?
- Is the requirement really necessary or does it represent an add-on feature that may not be essential to the objective of the system?

- Is each requirement bounded and unambiguous?
- Does each requirement have attribution? That is, is a source (generally, a specific individual) noted for each requirement?
- Do any requirements conflict with other requirements?
- Is each requirement achievable in the technical environment that will house the system or product?
- Is each requirement testable, once implemented?
- Does the requirements model properly reflect the information, function, and behavior of the system to be built?
- Has the requirements model been "partitioned" in a way that exposes progressively more detailed information about the system?
- Have requirements patterns been used to simplify the requirements model? Have all patterns been properly validated? Are all patterns consistent with customer requirements?

These and other questions should be asked and answered to ensure that the requirements model is an accurate reflection of stakeholder needs and that it provides a solid foundation for design.

g. REQUIREMENTS ANALYSIS

Requirements analysis results in the specification of software's operational characteristics, indicates software's interface with other system elements, and establishes constraints that software must meet.
The requirements modeling action results in one or more of the following types of models:

- ***Scenario-based models*** **of requirements from the point of view of various system "actors"**
- ***Data models*** **that depict the information domain for the problem**
- ***Class-oriented models*** **that represent object-oriented classes (attributes and operations) and the manner in which classes collaborate to achieve system**
- **requirements**
- ***Flow-oriented models*** **that represent the functional elements of the system and how they transform data as it moves through the system**
- ***Behavioral models*** **that depict how the software behaves as a consequence of external "events"**

These models provide a software designer with information that can be translated to architectural, interface, and component-level designs. Finally, the requirements model (and the software requirements specification) provides the developer and the customer with the means to assess quality once software is built.

➢ Overall Objectives and Philosophy

The requirements model must achieve three primary objectives: (1) to describe what the customer requires, (2) to establish a basis for the creation of a software design, and (3) to define a set of requirements that can be validated once the software is built. The analysis model bridges the gap between a system-level description that describes overall system or business functionality as it is achieved by applying software, hardware, data, human, and other system elements and a software design that describes the software's application architecture, user interface, and component-level structure. This relationship is illustrated in Figure 6.1.

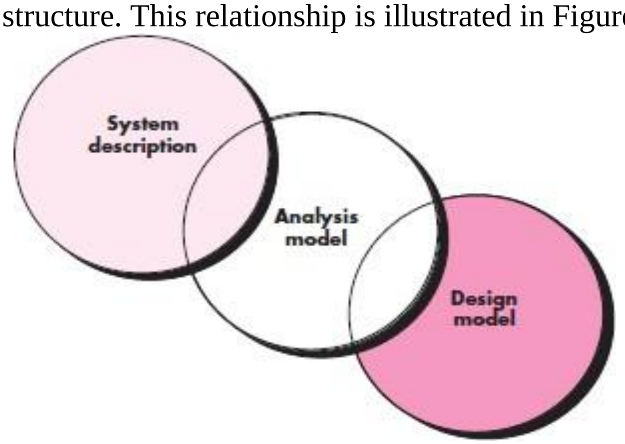


Figure 6.1: The requirements model as a bridge between the system description and the design model

➢ Analysis Rules of Thumb

Arlow and Neustadt suggest a number of worthwhile rules of thumb that should be followed when creating the analysis model:

- *The model should focus on requirements that are visible within the problem or business domain. The level of abstraction should be relatively high.* "Don't get bogged down in details" that try to explain how the system will work.
- *Each element of the requirements model should add to an overall understanding of software requirements and provide insight into the information domain, function, and behavior of the system.*
- *Delay consideration of infrastructure and other nonfunctional models until design.* That is, a database may be required, but the classes necessary to implement it, the functions required to access it, and the behavior that will be exhibited as it is used should be considered only after problem domain analysis has been completed.
- *Minimize coupling throughout the system.* It is important to represent relationships between classes and functions. However, if the level of "interconnectedness" is extremely high, effort should be made to reduce it.
- *Be certain that the requirements model provides value to all stakeholders.* Each constituency has its own use for the model. For example, business stakeholders should use the model to validate requirements; designers should use the model as a basis for design; QA people should use the model to help plan acceptance tests.
- *Keep the model as simple as it can be.* Don't create additional diagrams when they add no new information. Don't use complex notational forms, when a simple list will do.

➢ Domain Analysis

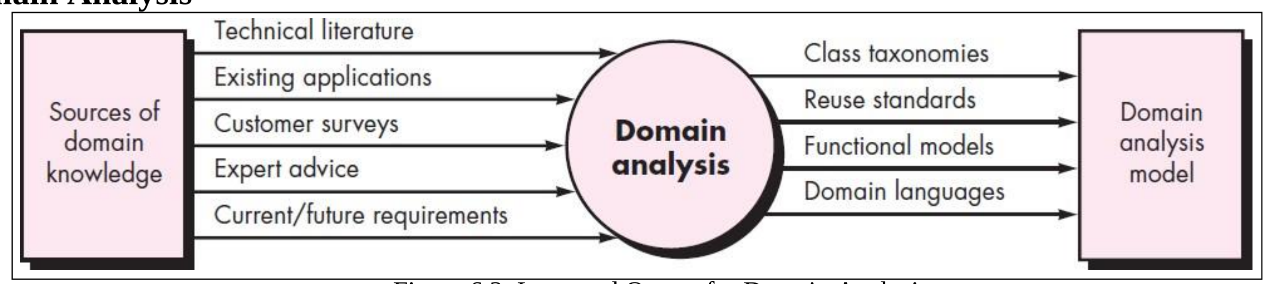


Figure 6.2: Input and Output for Domain Analysis

Firesmith describes domain analysis in the following way:

> Software domain analysis is the identification, analysis, and specification of common requirements from a specific application domain, typically for reuse on multiple projects within that application domain......... [Object-oriented domain analysis is] the identification, analysis, and specification of common, reusable capabilities within a specific application domain, in terms of common objects, classes, subassemblies, and frameworks.

The "specific application domain" can range from avionics to banking, from multimedia video games to software embedded within medical devices. The goal of domain analysis is straightforward: to find or create those analysis classes and/or analysis patterns that are broadly applicable so that they may be reused.

Figure 6.2 illustrates key inputs and outputs for the domain analysis process. Sources of domain knowledge are surveyed in an attempt to identify objects that can be reused across the domain.

➢ Requirements Modeling Approaches

One view of requirements modeling, called *structured analysis,* considers data and the processes that transform the data as separate entities. Data objects are modeled in a way that defines their attributes and relationships. Processes that manipulate data objects are modeled in a manner that shows how they transform data as data objects flow through the system.

A second approach to analysis modeling, called *object-oriented analysis,* focuses on the definition of classes and the manner in which they collaborate with one another to effect customer requirements.

Software teams often choose one approach and exclude all representations from the other. The question is not which is best, but rather, what combination of representations will provide stakeholders with the best model of software requirements and the most effective bridge to software design.

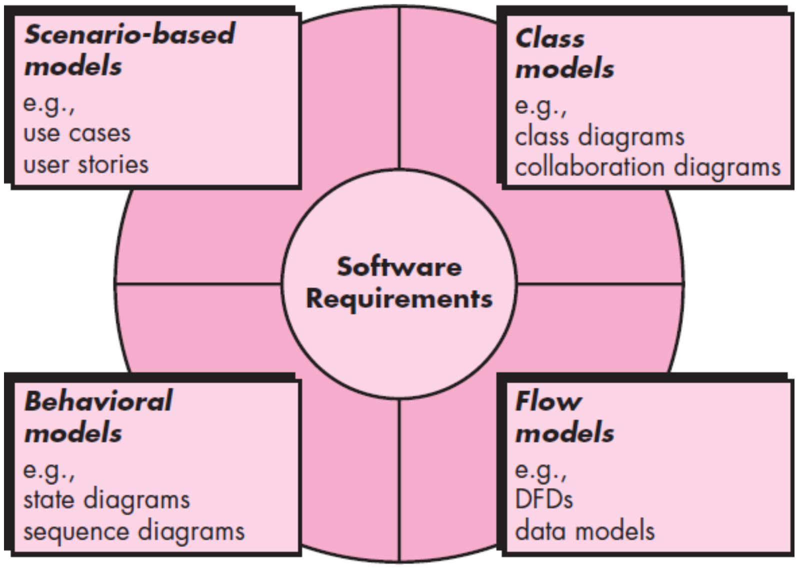


Figure 6.3: Elements of the analysis model

Each element of the requirements model (Figure 6.3) presents the problem from a different point of view. Scenario-based elements depict how the user interacts with the system and the specific sequence of activities that occur as the software is used. Class-based elements model the objects that the system will manipulate, the operations that will be applied to the objects to effect the manipulation, relationships (some hierarchical) between the objects, and the collaborations that occur between the classes that are defined. Behavioral elements depict how external events change the state of the system or the classes that reside within it. Finally, flow-oriented elements represent the system as an information transform, depicting how data objects are transformed as they flow through various system functions.

h. SCENARIO-BASED MODELING

Although the success of a computer-based system or product is measured in many ways, user satisfaction resides at the top of the list. If you understand how end users (and other actors) want to interact with a system, your software team will be better able to properly characterize requirements and build meaningful analysis and design models. Hence, requirements modeling with UML begins with the creation of scenarios in the form of use cases, activity diagrams, and swimlane diagrams.

➢ Creating a Preliminary Use Case

Alistair Cockburn characterizes a use case as a “contract for behavior”. The “contract” defines the way in which an actor uses a computer-based system to accomplish some goal. In essence, a use case captures the interactions that occur between producers and consumers of information and the system itself.

A use case describes a specific usage scenario in straightforward language from the point of view of a defined actor. But how do you know (1) what to write about, (2) how much to write about it, (3) how detailed to make your description, and (4) how to organize the description? These are the questions that must be answered if use cases are to provide value as a requirements modeling tool.

What to write about? Requirements gathering meetings, QFD, and other requirements engineering mechanisms are used to identify stakeholders, define the scope of the problem, specify overall operational goals, establish priorities, outline all known functional requirements, and describe the things (objects) that will be manipulated by the system. To begin developing a set of use cases, list the functions or activities performed by a specific actor. You can obtain these from a list of required system functions, through conversations with stakeholders, or by an evaluation of activity diagrams developed as part of requirements modeling. The *SafeHome* home surveillance function (subsystem) discussed in the sidebar identifies the following functions (an abbreviated list) that are performed by the **homeowner** actor:

- Select camera to view.
- Request thumbnails from all cameras.
- Display camera views in a PC window.

- Control pan and zoom for a specific camera.
- Selectively record camera output.
- Replay camera output.
- Access camera surveillance via the Internet.

As further conversations with the stakeholder (who plays the role of a homeowner) progress, the requirements gathering team develops use cases for each of the functions noted. In general, use cases are written first in an informal narrative fashion. If more formality is required, the same use case is rewritten using a structured format and reproduced later in this section as a sidebar. To illustrate, consider the function *access camera surveillance via the Internet— display camera views* **(ACS-DCV).** The stakeholder who takes on the role of the **homeowner** actor might write the following narrative:

Use case: Access camera surveillance via the Internet—display camera views (ACS-DCV)
Actor: homeowner

If I'm at a remote location, I can use any PC with appropriate browser software to log on to the *SafeHome Products* website. I enter my user ID and two levels of passwords and once I'm validated, I have access to all functionality for my installed *SafeHome* system. To access a specific camera view, I select "surveillance" from the major function buttons displayed.

I then select "pick a camera" and the floor plan of the house is displayed. I then select the camera that I'm interested in. Alternatively, I can look at thumbnail snapshots from all cameras simultaneously by selecting "all cameras" as my viewing choice. Once I choose a camera, I select "view" and a one-frame-per-second view appears in a viewing window that is identified by the camera ID. If I want to switch cameras, I select "pick a camera" and the original viewing window disappears and the floor plan of the house is displayed again.

I then select the camera that I'm interested in. A new viewing window appears. A variation of a narrative use case presents the interaction as an ordered sequence of user actions. Each action is represented as a declarative sentence. Revisiting the **ACS-DCV** function, you would write:

Use case: Access camera surveillance via the Internet—display camera views (ACS-DCV)
Actor: homeowner

1. The homeowner logs onto the *SafeHome Products* website.
2. The homeowner enters his or her user ID.
3. The homeowner enters two passwords (each at least eight characters in length).
4. The system displays all major function buttons.
5. The homeowner selects the "surveillance" from the major function buttons.
6. The homeowner selects "pick a camera."
7. The system displays the floor plan of the house.
8. The homeowner selects a camera icon from the floor plan.
9. The homeowner selects the "view" button.
10. The system displays a viewing window that is identified by the camera ID.
11. The system displays video output within the viewing window at one frame per second.

It is important to note that this sequential presentation does not consider any alternative interactions (the narrative is more free-flowing and did represent a few alternatives).
Use cases of this type are sometimes referred to as *primary scenarios*.

➢ Refining a Preliminary Use Case

A description of alternative interactions is essential for a complete understanding of the function that is being described by a use case. Therefore, each step in the primary scenario is evaluated by asking the following questions:

- *Can the actor take some other action at this point?*
- *Is it possible that the actor will encounter some error condition at this point?* If so, what might it be?
- *Is it possible that the actor will encounter some other behavior at this point (e.g., behavior that is invoked by some event outside the actor's control)?*

If so, what might it be? Answers to these questions result in the creation of a set of *secondary scenarios* that are part of the original use case but represent alternative behavior. For example, consider steps 6 and 7 in the primary scenario presented earlier:

6. The homeowner selects "pick a camera."

7. The system displays the floor plan of the house.
Can the actor take some other action at this point? The answer is "yes." Referring to the free-flowing narrative, the actor may choose to view thumbnail snapshots of all cameras simultaneously. Hence, one secondary scenario might be "View thumbnail snapshots for all cameras."
Is it possible that the actor will encounter some error condition at this point? Any number of error conditions can occur as a computer-based system operates. In this context, we consider only error conditions that are likely as a direct result of the action described in step 6 or step 7. Again the answer to the question is "yes." A floor plan with camera icons may have never been configured. Hence, selecting "pick a camera" results in an error condition: "No floor plan configured for this house."9 This error condition becomes a secondary scenario.
Is it possible that the actor will encounter some other behavior at this point? Again the answer to the question is "yes." As steps 6 and 7 occur, the system may encounter an alarm condition. This would result in the system displaying a special alarm notification (type, location, system action) and providing the actor with a number of options relevant to the nature of the alarm. Because this secondary scenario can occur at any time for virtually all interactions, it will not become part of the **ACS-DCV** use case. Rather, a separate use case—**Alarm condition encountered**—would be developed and referenced from other use cases as required. Each of the situations described in the preceding paragraphs is characterized as a use-case exception. An *exception* describes a situation (either a failure condition or an alternative chosen by the actor) that causes the system to exhibit somewhat different behavior.

➢ Writing a Formal Use Case

The informal use cases are sometimes sufficient for requirements modeling. However, when a use case involves a critical activity or describes a complex set of steps with a significant number of exceptions, a more formal approach may be desirable.
The **ACS-DCV** use case shown in the sidebar follows a typical outline for formal use cases. The *goal in context* identifies the overall scope of the use case. The *precondition* describes what is known to be true before the use case is initiated.
The *trigger* identifies the event or condition that "gets the use case started". The *scenario* lists the specific actions that are required by the actor and the appropriate system responses. *Exceptions* identify the situations uncovered as the preliminary use case is refined.
Additional headings may or may not be included and are reasonably self-explanatory. In many cases, there is no need to create a graphical representation of a usage scenario. However, diagrammatic representation can facilitate understanding, particularly when the scenario is complex. As we noted earlier in this book, UML does provide use-case diagramming capability. Figure 6.4 depicts a preliminary use-case diagram for the *SafeHome* product. Each use case is represented by an oval. Only the **ACS-DCV** use case has been discussed in this section.

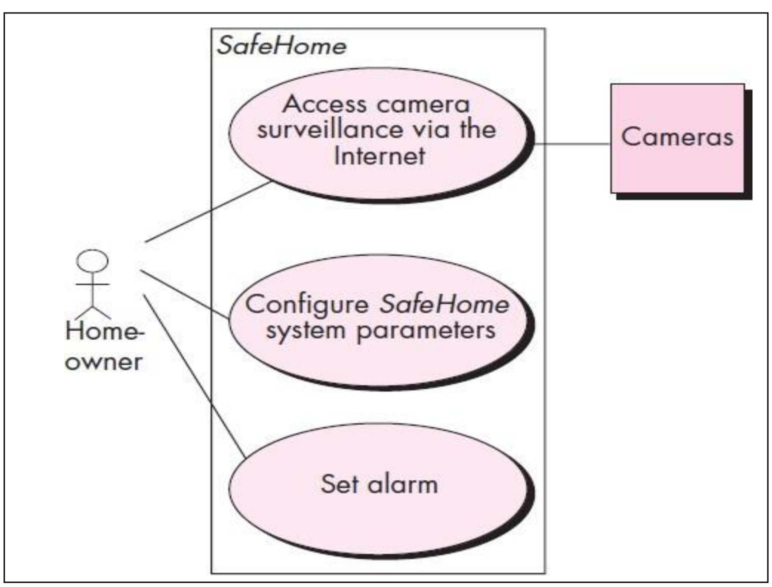


Figure 6.4: Preliminary use-case diagram for the *SafeHome* system

Use case: InitiateMonitoring
Primary actor: Homeowner.
Goal in context: To set the system to monitor sensors when the homeowner leaves the house or remains inside.
Preconditions: System has been programmed for a password and to recognize various sensors.
Trigger: The homeowner decides to "set" the system, i.e., to turn on the alarm functions.
Scenario: 1. Homeowner: observes control panel
2. Homeowner: enters password
3. Homeowner: selects "stay" or "away"
4. Homeowner: observes read alarm light to indicate that SafeHome has been armed
Exceptions: 1. Control panel is not ready: homeowner checks all sensors to determine which are open; closes them.
2. Password is incorrect (control panel beeps once): homeowner reenters correct password.
3. Password not recognized: monitoring and response subsystem must be contacted to reprogram password.
4. Stay is selected: control panel beeps twice and a stay light is lit; perimeter sensors are activated.
5. Away is selected: control panel beeps three times and an away light is lit; all sensors are activated.
Priority: Essential, must be implementation.

i. REQUIREMENTS MODELING STRATEGIES

One view of requirements modeling, called *structured analysis,* considers data and the processes that transform the data as separate entities. Data objects are modeled in a way that defines their attributes and relationships. Processes that manipulate data objects are modeled in a manner that shows how they transform data as data objects flow through the system. A second approach to analysis modeled, called *object-oriented analysis,* focuses on the definition of classes and the manner in which they collaborate with one another to effect customer requirements.

j. FLOW-ORIENTED MODELING

The DFD takes an input-process-output view of a system. That is, data objects flow into the software, are transformed by processing elements, and resultant data objects flow out of the software. Data objects are represented by labeled arrows, and transformations are represented by circles (also called bubbles). The DFD is presented in a hierarchical fashion. That is, the first data flow model (sometimes called a level 0 DFD or *contextdiagram*) represents the system as a whole. Subsequent data flow diagrams refine the context diagram, providing increasing detail with each subsequent level.

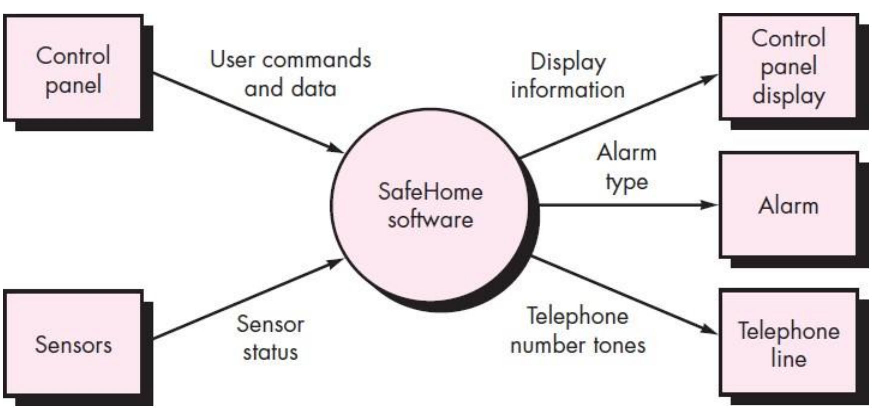


Figure 7.1: Context-level DFD for the *SafeHome* security function

➢ Creating a Data Flow Model

The data flow diagram enables you to develop models of the information domain and functional domain. As the DFD is refined into greater levels of detail, you perform an implicit functional decomposition of the system. At the same time, the DFD refinement results in a corresponding refinement of data as it moves through the processes that embody the application.

A few simple guidelines can aid immeasurably during the derivation of a data flow diagram: (1) the level 0 data flow diagram should depict the software/system as a single bubble; (2) primary input and output should be carefully noted; (3) refinement should begin by isolating candidate processes, data objects, and data stores to be represented at the next level; (4) all arrows and bubbles should be labeled with meaningful names;

(5) information flow continuity must be maintained from level to level,2 and (6) one bubble at a time should be refined. There is a natural tendency to overcomplicate the data flow diagram. This occurs when you attempt to show too much detail too early or represent procedural aspects of the software in lieu of information flow.

To illustrate the use of the DFD and related notation, we again consider the *SafeHome* security function. A level 0 DFD for the security function is shown in Figure 7.1. The primary *external entities* (boxes) produce information for use by the system and consume information generated by the system. The labeled arrows represent data objects or data object hierarchies. For example, **user commands and data** encompasses all configuration commands, all activation/deactivation commands, all miscellaneous interactions, and all data that are entered to qualify or expand a command.

The level 0 DFD must now be expanded into a level 1 data flow model. But how do we proceed? Following an approach suggested to you should apply a “grammatical parse” to the use case narrative that describes the context-level bubble. That is, we isolate all nouns (and noun phrases) and verbs (and verb phrases) in a *SafeHome* processing narrative derived during the first requirements gathering meeting.

The SafeHome security function *enables* the homeowner to *configure* the security system when it is *installed*, *monitors* all sensors *connected* to the security system, and *interacts* with the homeowner through the Internet, a PC, or a control panel.

During installation, the *SafeHome* PC is used to *program* and *configure* the system. Each sensor is assigned a number and type, a master password is programmed for *arming* and *disarming* the system, and telephone number(s) are *input* for *dialing* when a sensor event occurs.

When a sensor event is *recognized*, the software *invokes* an audible alarm attached to the system. After a delay time that is specified by the homeowner during system configuration activities, the software dials a telephone number of a monitoring service, *provides* information about the location, *reporting* the nature of the event that has been detected. The telephone number will be *redialed* every 20 seconds until telephone connection is *obtained.*

The homeowner *receives* security information via a control panel, the PC, or a browser, collectively called an interface. The interface *displays* prompting messages and system status information on the control panel, the PC, or the browser window. Homeowner interaction takes the following form . . . Referring to the grammatical parse, verbs are *SafeHome* processes and can be represented as bubbles in a subsequent DFD. Nouns are either external entities (boxes), data or control objects (arrows), or data stores (double lines). Recall that nouns and verbs can be associated with one another (e.g., each sensor is assigned a number and type; therefore number and type are attributes of the data object **sensor**). Therefore, by performing a grammatical parse on the processing narrative for a bubble at any DFD level, you can generate much useful information about how to proceed with the refinement to the next level. Using this information, a level 1 DFD is shown in Figure 7.2. The context level process shown in Figure 7.1 has been expanded into six processes derived from an examination of the grammatical parse. Similarly, the information flow between processes at level 1 has been derived from the parse. In addition, information flow continuity is maintained
between levels 0 and 1.

The processes represented at DFD level 1 can be further refined into lower levels. For example, the process *monitor sensors* can be refined into a level 2 DFD as shown in Figure 7.3. Note once again that information flow continuity has been maintained between levels.

The refinement of DFDs continues until each bubble performs a simple function. That is, until the process represented by the bubble performs a function that would be easily implemented as a program component.

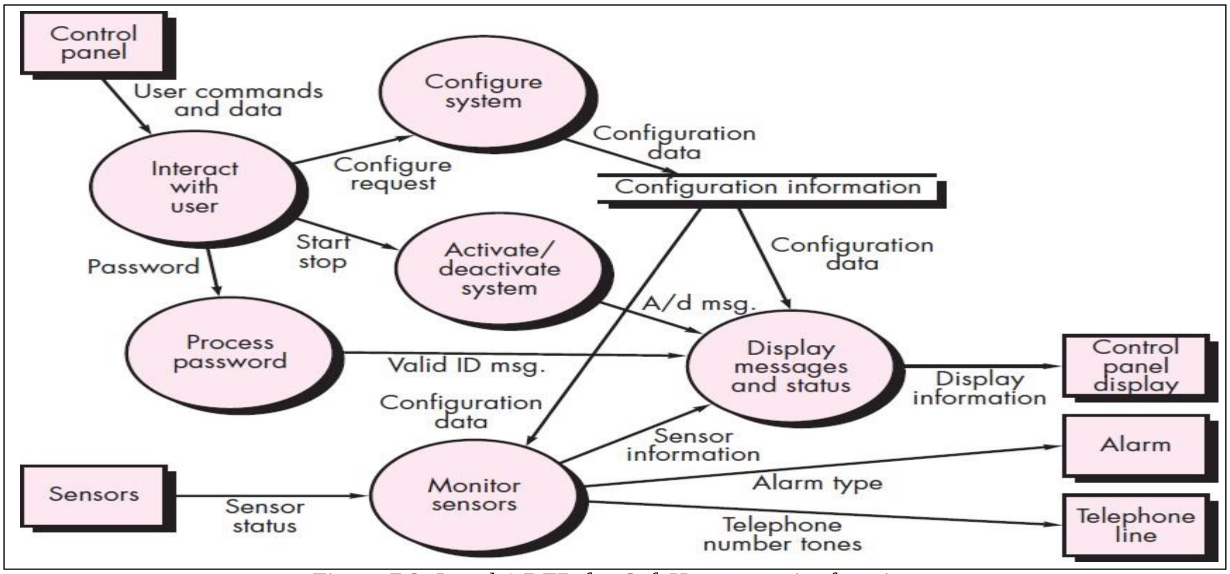


Figure 7.2: Level 1 DFD for *SafeHome* security function

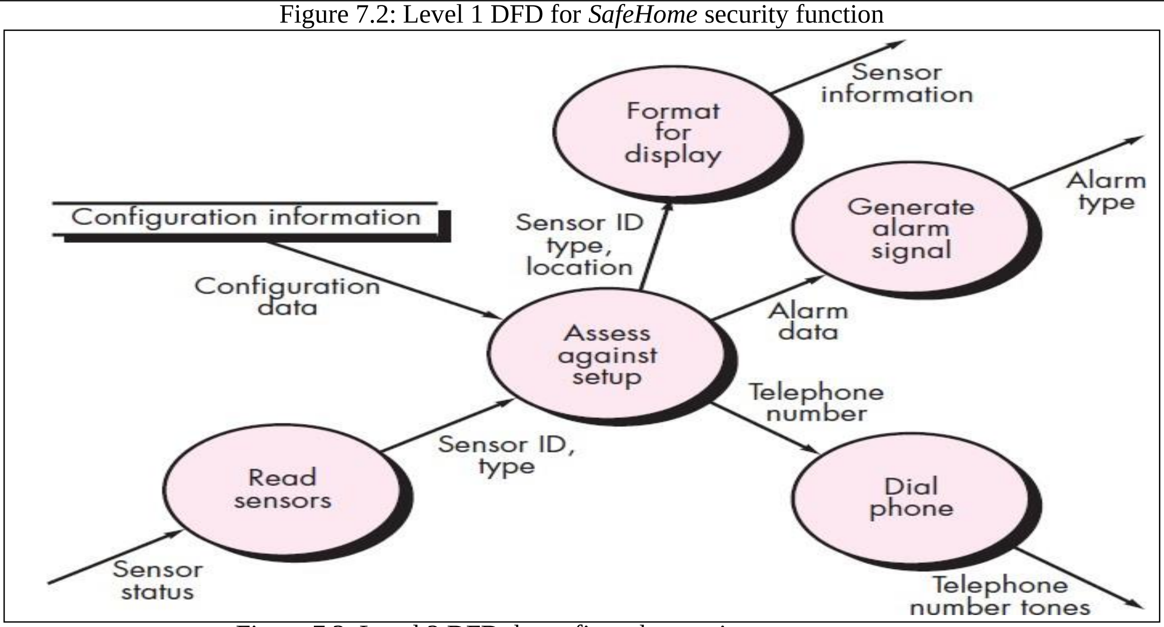


Figure 7.3: Level 2 DFD that refines the monitor sensors process

➢ Creating a Control Flow Model

A large class of applications are "driven" by events rather than data, produce control information rather than reports or displays, and process information with heavy concern for time and performance. Such applications require the use of *control flow modeling* in addition to data flow modeling.

I have already noted that an event or control item is implemented as a Boolean value (e.g., true or false, on or off, 1 or 0) or a discrete list of conditions (e.g., empty, jammed, full). To select potential candidate events, the following guidelines are suggested:

- List all sensors that are "read" by the software.
- List all interrupt conditions.
- List all "switches" that are actuated by an operator.
- List all data conditions.
- Recalling the noun/verb parse that was applied to the processing narrative, review all "control items" as possible control specification inputs/outputs.
- Describe the behavior of a system by identifying its states, identify how each state is reached, and define the transitions between states.
- Focus on possible omissions—a very common error in specifying control; for example, ask: "Is there any other way I can get to this state or exit from it?"

➢ The Control Specification

A *control specification* (CSPEC) represents the behavior of the system (at the level from which it has been referenced) in two different ways. The CSPEC contains a state diagram that is a sequential specification of behavior. It can also contain a program activation table—a combinatorial specification of behavior.

Figure 7.4 depicts a preliminary state diagram for the level 1 control flow model for *SafeHome*. The diagram indicates how the system responds to events as it traverses the four states defined at this level.

For example, the state diagram (Figure 7.4) indicates that the transitions from the **Idle** state can occur if the system is reset, activated, or powered off. If the system is activated (i.e., alarm system is turned on), a transition to the **Monitoring- SystemStatus** state occurs, display messages are changed as shown, and the process *monitorAndControlSystem* is invoked. Two transitions occur out of the **MonitoringSystemStatus** state—(1) when the system is deactivated, a transition occurs back to the **Idle** state; (2) when a sensor is triggered into the **ActingOnAlarm** state. All transitions and the content of all states are considered during the review.

A somewhat different mode of behavioral representation is the process activation table. The PAT represents information contained in the state diagram in the context of processes, not states. That is, the table indicates which processes (bubbles) in the flow model will be invoked when an event occurs. The PAT can be used as a guide for a designer who must build an executive that controls the processes represented at this level. A PAT for the level 1 flow model of *SafeHome* software is shown in Figure 7.5.

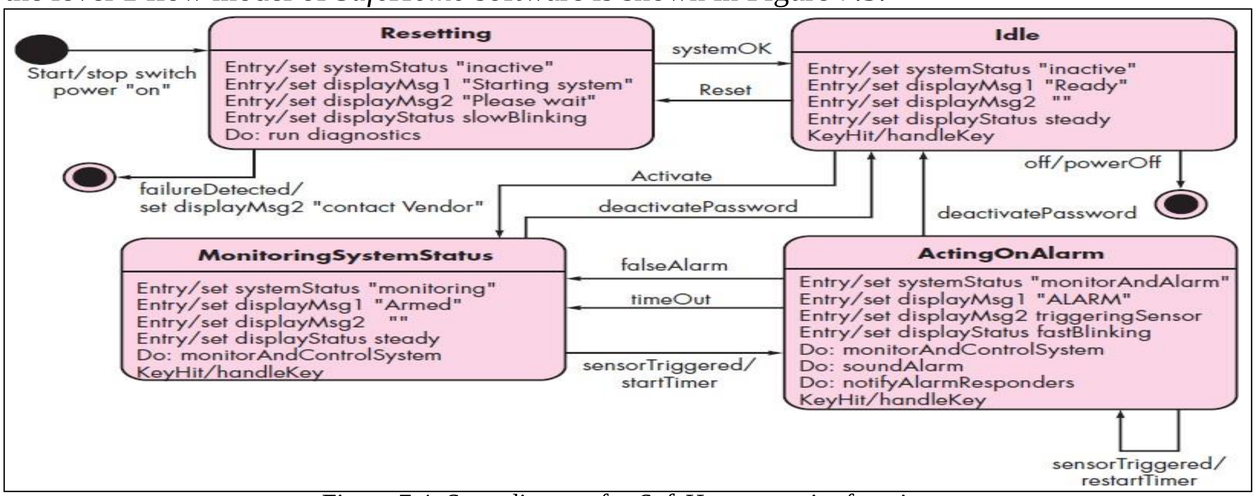


Figure 7.4: State diagram for *SafeHome* security function

input events						
sensor event	0	0	0	0	1	0
blink flag	0	0	1	1	0	0
start stop switch	0	1	0	0	0	0
display action status complete	0	0	0	1	0	0
in-progress	0	0	1	0	0	0
time out	0	0	0	0	0	1
output						
alarm signal	0	0	0	0	1	0
process activation						
monitor and control system	0	1	0	0	1	1
activate/deactivate system	0	1	0	0	0	0
display messages and status	1	0	1	1	1	1
interact with user	1	0	0	1	0	1

Figure 7.5: Process activation table for *SafeHome* security function

➢ The Process Specification

The *process specification* (PSPEC) is used to describe all flow model processes that appear at the final level of refinement. The content of the process specification can include narrative text, a program design language (PDL) description of the process algorithm, mathematical equations, tables, or UML activity diagrams. By providing a PSPEC to accompany each bubble in the flow model, you can create a “mini-spec” that serves as a guide for design of the software component that will implement the bubble.

i. DATA MODELING CONCEPTS

If software requirements include the need to create, extend, or interface with a database or if complex data structures must be constructed and manipulated, the software team may choose to create a *data model* as part of overall requirements modeling. A software engineer or analyst defines all data objects that are processed within the system, the relationships between the data objects, and other information that is pertinent to the relationships. The *entity-relationship diagram* (ERD) addresses these issues and represents all data objects that are entered, stored, transformed, and produced within an application.

➢ Data Objects

A *data object* is a representation of composite information that must be understood by software. By *composite information,* I mean something that has a number of different properties or attributes. Therefore, width (a single value) would not be a valid data object, but **dimensions** (incorporating height, width, and depth) could be defined as an object.

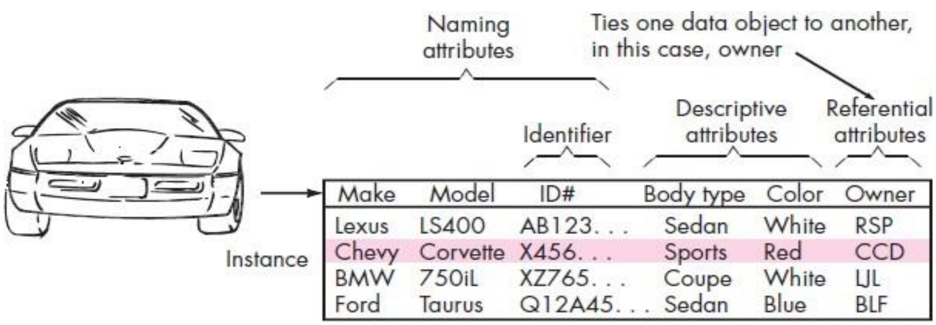
A data object can be an external entity (e.g., anything that produces or consumes information), a thing (e.g., a report or a display), an occurrence (e.g., a telephone call) or event (e.g., an alarm), a role (e.g., salesperson), an organizational unit (e.g., accounting department), a place (e.g., a warehouse), or a structure (e.g., a file). For example, a **person** or a **car** can be viewed as a data object in the sense that either can be defined in terms of a set of attributes. The description of the data object incorporates the data object and all of its attributes.

A data object encapsulates data only—there is no reference within a data object to operations that act on the data.Therefore, the data object can be represented as a table as shown in Figure 6.7. The headings in the table reflect attributes of the object.

In this case, a car is defined in terms of make, model, ID number, body type, color, and owner. The body of the table represents specific instances of the data object. For example, a Chevy Corvette is an instance of the data object **car.**

➢ Data Attributes

Data attributes define the properties of a data object and take on one of three different characteristics. They can be used to (1) name an instance of the data object, (2) describe the instance, or (3) make reference to another instance in another table. In addition, one or more of the attributes must be defined as an identifier—that is, the identifier attribute becomes a "key" when we want to find an instance of the data object. In some cases, values for the identifier(s) are unique, although this is not a requirement. Referring to the data object **car,** a reasonable identifier might be the ID number.



Make	Model	ID#	Body type	Color	Owner
Lexus	LS400	AB123. . .	Sedan	White	RSP
Chevy	Corvette	X456. . .	Sports	Red	CCD
BMW	750iL	XZ765. . .	Coupe	White	LJL
Ford	Taurus	Q12A45. . .	Sedan	Blue	BLF

Figure 6.7. Tabular representation of data objects

- **Relationships**

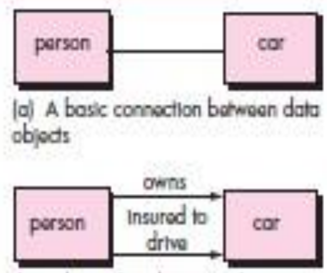


FIGURE 6.8
Relationships between data objects

(a) A basic connection between data objects

(b) Relationships between data objects

Data objects are connected to one another in different ways. Consider the two data objects, **person** and **car.** These objects can be represented using the simple notation illustrated in Figure 6.8a. A connection is established between **person** and **car** because the two objects are related. But what are the relationships? To determine the answer, you should understand the role of people (owners, in this case) and cars within the context of the software to be built. You can establish a set of object/relationship pairs that define the relevant relationships. For example,

- A person *owns* a car.
- A person *is insured to drive* a car.

j. CLASS-BASED MODELING

Class-based modeling represents the objects that the system will manipulate, the operations (also called methods or services) that will be applied to the objects to effect the manipulation, relationships (some hierarchical) between the objects, and the collaborations that occur between the classes that are defined. The elements of a class-based model include classes and objects, attributes, operations, class responsibility- collaborator (CRC) models, collaboration diagrams, and packages.

➢ Identifying Analysis Classes

Analysis classes manifest themselves in one of the following ways:

- *External entities* (e.g., other systems, devices, people) that produce or consume information to be used by a computer-based system.
- *Things* (e.g., reports, displays, letters, signals) that are part of the information domain for the problem.
- *Occurrences or events* (e.g., a property transfer or the completion of a series of robot movements) that occur within the context of system operation.
- *Roles* (e.g., manager, engineer, salesperson) played by people who interact with the system.
- *Organizational units* (e.g., division, group, team) that are relevant to an application.
- *Places* (e.g., manufacturing floor or loading dock) that establish the context of the problem and the overall function of the system.
- *Structures* (e.g., sensors, four-wheeled vehicles, or computers) that define a class of objects or related classes of objects.

To illustrate how analysis classes might be defined during the early stages of modeling, consider a grammatical parse for a processing narrative for the *SafeHome* security function.

The SafeHome security function *enables* the homeowner to *configure* the security system when it is *installed*, *monitors* all sensors *connected* to the security system, and *interacts* with the homeowner through the Internet, a PC, or a control panel. During installation, the SafeHome PC is used to *program* and *configure* the system. Each sensor is assigned a number and type, a master password is programmed for *arming* and *disarming* the system, and telephone number(s) are *input* for *dialing* when a sensor event occurs.

When a sensor event is *recognized*, the software *invokes* an audible alarm attached to the system. After a delay time that is *specified* by the homeowner during system configuration activities, the software dials a telephone number of a monitoring service, *provides* information about the location, *reporting* the nature of the event that has been detected. The telephone number will be *redialed* every 20 seconds until telephone connection is *obtained.*

The homeowner *receives* security information via a control panel, the PC, or a browser, collectively called an interface. The interface *displays* prompting messages and system status information on the control panel, the PC ,or the browser window. Homeowner interaction takes the following form . . .

Extracting the nouns, we can propose a number of potential classes:

Potential Class	General Classification
homeowner	role or external entity
sensor	external entity
control panel	external entity
installation	occurrence
system (alias security system)	thing
number, type	not objects, attributes of sensor
master password	thing
telephone number	thing
sensor event	occurrence
audible alarm	external entity
monitoring service	organizational unit or external entity

The list would be continued until all nouns in the processing narrative have been considered. Note that I call each entry in the list a potential object. You must consider each further before a final decision is made. Coad and Yourdon suggest six selection characteristics that should be used as you consider each potential class for inclusion in the analysis model:

1. *Retained information.* The potential class will be useful during analysis only if information about it must be remembered so that the system can function.
2. *Needed services.* The potential class must have a set of identifiable operations that can change the value of its attributes in some way.
3. *Multiple attributes.* During requirement analysis, the focus should be on "major" information; a class with a single attribute may, in fact, be useful during design, but is probably better represented as an attribute of another class during the analysis activity.
4. *Common attributes.* A set of attributes can be defined for the potential class and these attributes apply to all instances of the class.
5. *Common operations.* A set of operations can be defined for the potential class and these operations apply to all instances of the class.
6. *Essential requirements.* External entities that appear in the problem space and produce or consume information essential to the operation of any solution for the system will almost always be defined as classes in the requirements model.

To be considered a legitimate class for inclusion in the requirements model, a potential object should satisfy all (or almost all) of these characteristics. The decision for inclusion of potential classes in the analysis model is somewhat subjective, and later evaluation may cause an object to be discarded or reinstated. However, the first step of class-based modeling is the definition of classes, and decisions (even subjective ones) must be made. With this in mind, you should apply the selection characteristics to the list of potential *SafeHome* classes:

Potential Class	Characteristic Number That Applies
homeowner	rejected: 1, 2 fail even though 6 applies
sensor	accepted: all apply
control panel	accepted: all apply
installation	rejected
system (alias security function)	accepted: all apply
number, type	rejected: 3 fails, attributes of sensor
master password	rejected: 3 fails
telephone number	rejected: 3 fails
sensor event	accepted: all apply
audible alarm	accepted: 2, 3, 4, 5, 6 apply
monitoring service	rejected: 1, 2 fail even though 6 applies

It should be noted that (1) the preceding list is not all-inclusive, additional classes would have to be added to complete the model; (2) some of the rejected potential classes will become attributes for those classes that were accepted (e.g., number and type are attributes of **Sensor,** and master password and telephone number may become attributes of **System**); (3) different statements of the problem might cause different "accept or reject" decisions to be made (e.g., if each homeowner had an individual password or was identified by voice print, the **Homeowner** class would satisfy characteristics 1 and 2 and would have been accepted).

➢ Specifying Attributes

Attributes describe a class that has been selected for inclusion in the requirements model. In essence, it is the attributes that define the class—that clarify what is meant by the class in the context of the problem space. For example, if we were to build a system that tracks baseball statistics for professional baseball players, the attributes of the class **Player** would be quite different than the attributes of the same class when it is used in the context of the professional baseball pension system.

In the former, attributes such as name, position, batting average, fielding percentage, years played, and games played might be relevant. For the latter, some of these attributes would be meaningful, but others would be replaced (or augmented) by attributes like average salary, credit toward full vesting, pension plan options chosen, mailing address, and the like.

To develop a meaningful set of attributes for an analysis class, you should study each use case and select those "things" that reasonably "belong" to the class. In addition, the following question should be answered for each class: "What data items (composite and/or elementary) fully define this class in the context of the problem at hand?"

To illustrate, we consider the **System** class defined for *SafeHome*. A homeowner can configure the security function to reflect sensor information, alarm response information, activation/deactivation information, identification information, and so forth. We can represent these composite data items in the following manner:

identification information = system ID + verification phone number + system status

alarm response information = delay time + telephone number

activation/deactivation information = master password + number of allowable tries + temporary password

Each of the data items to the right of the equal sign could be further defined to an elementary level, but for our purposes, they constitute a reasonable list of attributes for the **System** class (shaded portion of Figure 6.9). Sensors are part of the overall *SafeHome* system, and yet they are not listed as data items or as attributes in Figure 6.9. **Sensor** has already been defined as a class, and multiple **Sensor** objects will be associated with the **System** class. In general, we avoid defining an item as an attribute if more than one of the items is to be associated with the class.

➢ Defining Operations

Operations define the behavior of an object. Although many different types of operations exist, they can generally be divided into four broad categories: (1) operations that manipulate data in some way (e.g., adding, deleting, reformatting, selecting), (2) operations that perform a computation, (3) operations that inquire about the state of an object, and (4) operations that monitor an object for the occurrence of a controlling event. These functions are accomplished by operating on attributes and/or associations (Section 6.5.5). Therefore, an operation must have "knowledge" of the nature of the class' attributes and associations.

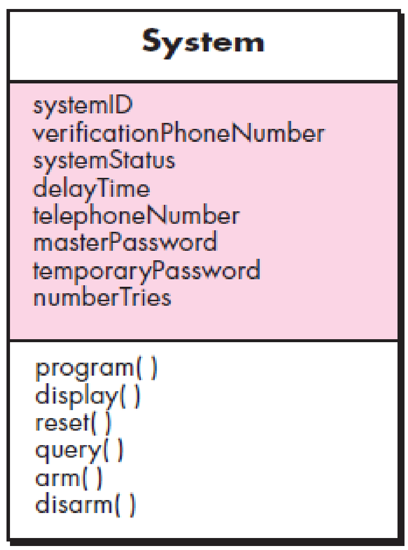


Figure 6.9: Class diagram for the system class

As a first iteration at deriving a set of operations for an analysis class, you can again study a processing narrative (or use case) and select those operations that reasonably belong to the class. To accomplish this, the grammatical parse is again studied and verbs are isolated. Some of these verbs will be legitimate operations and can be easily connected to a specific class. For example, from the *SafeHome* processing narrative presented earlier in this chapter, we see that "sensor is *assigned* a number and type" or "a master password is *programmed* for *arming and disarming* the system." These phrases indicate a number of things:

- That an *assign()* operation is relevant for the **Sensor** class.
- That a *program()* operation will be applied to the **System** class.
- That *arm()* and *disarm()* are operations that apply to **System** class.

Upon further investigation, it is likely that the operation *program()* will be divided into a number of more specific suboperations required to configure the system. For example, *program()* implies specifying phone numbers, configuring system characteristics (e.g., creating the sensor table, entering alarm characteristics), and entering password(s). But for now, we specify *program()* as a single operation.

In addition to the grammatical parse, you can gain additional insight into other operations by considering the communication that occurs between objects. Objects communicate by passing messages to one another. Before continuing with the specification of operations, I explore this matter in a bit more detail.

k. SRS

The Software Requirements Specification is produced at the conclusion of the analysis task. The function and performance allocated to software as part of system engineering are refined by establishing a complete information description, a detailed functional description, a representation of system behavior, an indication of performance requirements and design constraints, appropriate validation criteria, and other information pertinent to requirements. The National Bureau of Standards, IEEE (Standard No. 830-1984), and the U.S. Department of Defense have all proposed candidate formats for software requirements specifications (as well as other software engineering documentation).

The Introduction of the software requirements specification states the goals and objectives of the software, describing it in the context of the computer-based system. Actually, the Introduction may be nothing more than the software scope of the planning document.

The Information Description provides a detailed description of the problem that the software must solve. Information content, flow, and structure are documented. Hardware, software, and human interfaces are described for external system elements and internal software functions.

A description of each function required to solve the problem is presented in the Functional Description. A processing narrative is provided for each function, design constraints are stated and justified, performance characteristics are stated, and one or more diagrams are included to graphically represent the overall structure of the software and interplay among software functions and other system elements. The Behavioral Description section of the specification examines the operation of the software as a consequence of external events and internally generated control characteristics.

Validation Criteria is probably the most important and, ironically, the most often neglected section of the Software Requirements Specification. How do we recognize a successful implementation? What classes of tests must be conducted to validate function, performance, and constraints? We neglect this section because completing it demands a thorough understanding of software requirements—something that we often do not have at this stage. Yet, specification of validation criteria acts as an implicit review of all other requirements. It is essential that time and attention be given to this section.

Finally, the specification includes a Bibliography and Appendix. The bibliography contains references to all documents that relate to the software. These include other software engineering documentation, technical references, vendor literature, and standards. The appendix contains information that supplements the specifications. Tabular data, detailed description of algorithms, charts, graphs, and other material are presented as appendixes.