KULeuven DistriNet Research Group

Threat Modeling

Frank Piessens (Frank.Piessens@cs.kuleuven.be)

Overview

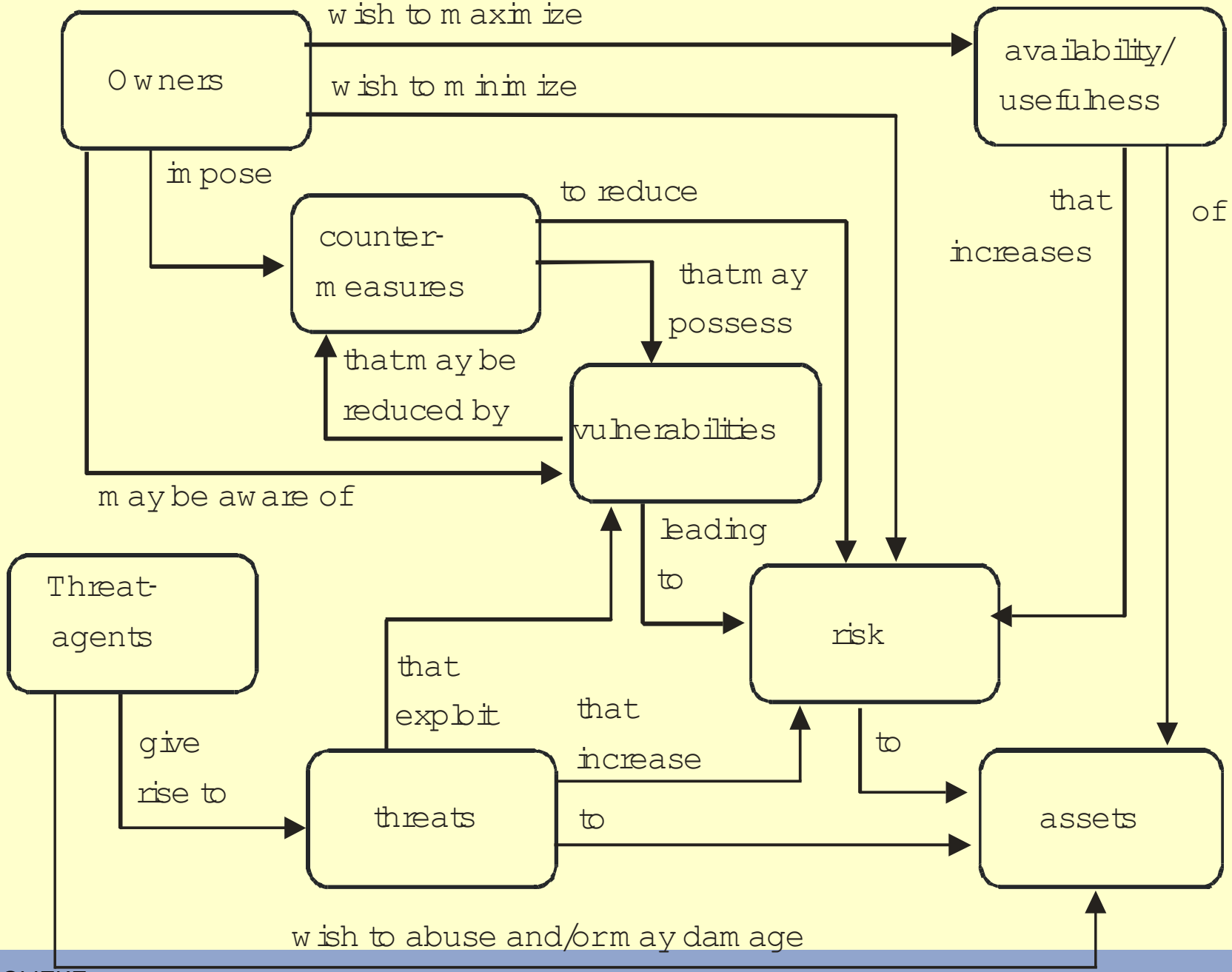
- Introduction
- Key Concepts
  - Threats, Vulnerabilities, Countermeasures
  - Example
- Microsoft's Threat Modeling Process
- Conclusion

Threat modeling

- Threat modeling is an activity early in the software development lifecycle
  - Primary goal: get a good view on possible threats to the system being developed
- Threat modeling can be done on various levels of abstraction
  - System level
    - E.g. Threat modeling of the Internet e-mail system
  - Application or component level
    - E.g. Threat modeling of the e-mail client software

Overview

- Introduction
- Key Concepts
  - Threats, Vulnerabilities, Countermeasures
  - Example
- Microsoft's Threat Modeling Process
- Conclusion


Owners
wish to maximize
wish to minimize
availability/
usefulness
impose
counter-
measures
to reduce
that
increases
of
that may
possess
that may be
reduced by
vulnerabilities
may be aware of
leading
to
Threat-
agents
risk
that
exploit
that
increase
to
give
rise to
threats
to
assets
wish to abuse and/or may damage

Threats versus Security Goals

- In a first approximation, threats and security goals are each others negation:
  - A security goal is a statement of intent to counter identified threats
  - A threat is the intention of a threat agent to break a security goal

Typical Threats

- Information disclosure
  - Threat: Information leaks to threat agents that should not be able to get access to that information
  - Corresponding Security Goals:
    - **Data Confidentiality**: protecting data against unauthorized reading
    - **Access Control**: preventing unauthorized access to software functions
  - Example: stealing of credit card numbers

Typical Threats

- Information tampering
  - Threat: threat agents tamper with data they should not be able to modify
  - Corresponding Security Goals:
    - **Data Integrity**: protecting data against unauthorized writing
    - **Data Origin Authentication**: verifying the claimed identity of the originator of a message
    - **Access Control**: preventing unauthorized access to software functions
  - Example: changing the price of purchased goods

Typical Threats

- Repudiation
  - Threat: threat agent denies involvement in an event
  - Corresponding Security Goals:
    - **Non-repudiation**: the provision of irrefutable evidence about what happened and who was involved
    - **Audit**: chronological record of system activities to enable the reconstruction of events
  - Example: denying placement of a stock order

Typical Threats

- Denial of Service
  - Threat: threat agent destroys the usefulness of the system for legitimate users
  - Corresponding Security Goals:
    - **Availability:** ensuring availability of the system to legitimate users
  - Example: Distributed Flood Attack

Typical Threats

- Elevation of privilege
  - Threat: threat agent gets more access to information/communication/processing resources than he is authorized for
  - Corresponding Security Goals:
    - **Access Control**: preventing unauthorized access to software functions
    - **Entity Authentication**: verifying the claimed identity of a party one is interacting with
  - Example: “getting root”

Typical Threats

- Spoofing
  - Threat: Threat agent pretends to be someone/something he is not
  - Corresponding Security Goals:
    - **Entity Authentication**: verifying the claimed identity of a party one is interacting with
    - **Data Origin Authentication**: verifying the originator of a message
  - Example: phishing

Vulnerabilities

- A vulnerability is an aspect of (a component of) the system that allows a threat agent to realize a threat (i.e. break a security goal)
- Hence, vulnerabilities are relative to the capabilities of the threat agent
  - E.g. the system can be vulnerable to insiders but not to outsiders

Vulnerabilities

- Vulnerabilities arise through failures in:
  - Requirements,
    - Failure to identify all relevant assets, or specific threats
    - E.g. protecting against the threat of downloaded malicious code was not recognized as a requirement for OS security in the eighties
  - Construction,
    - Vulnerabilities in security components
      - E.g. a weak cryptographic algorithm
    - Vulnerabilities in application functionality
      - E.g. buffer overflows, SQL injection, …
  - Operation
    - E.g. Setting an incorrect policy

Vulnerabilities

- Vulnerabilities can exist in the different layers of a software system
  - Application, e.g. SQL injection
  - Programming language runtime, e.g. type confusion
  - Middleware, e.g. open management interface
  - Operating system, e.g. FAT32 file system
  - Hardware, e.g. side-channels

Countermeasures

- Countermeasures are the mechanisms used to:
  - Reduce vulnerabilities, and hence:
    - Realize security goals
    - Counter threats

Countermeasures

- Countermeasures can be:
  - Preventive: avoid vulnerability
  - Detective: detect vulnerability exploitation
  - Reactive: handle incidents
- Countermeasures can be taken by:
  - Software engineers, programmers who develop software
  - Administrators, system managers who deploy software
  - …

Software Engineer Countermeasures

- For vulnerabilities introduced in the requirements phase:
  - Security reqs engineering, threat analysis and modeling
- To address threats collected during requirements engineering
  - Security technologies
    - cryptography, access control mechanisms, authentication mechanisms, …
- For vulnerabilities introduced during construction:
  - Secure programming, static analysis, safe languages,…
- For vulnerabilities introduced during operation:
  - Documentation, operational procedures, secure defaults, …

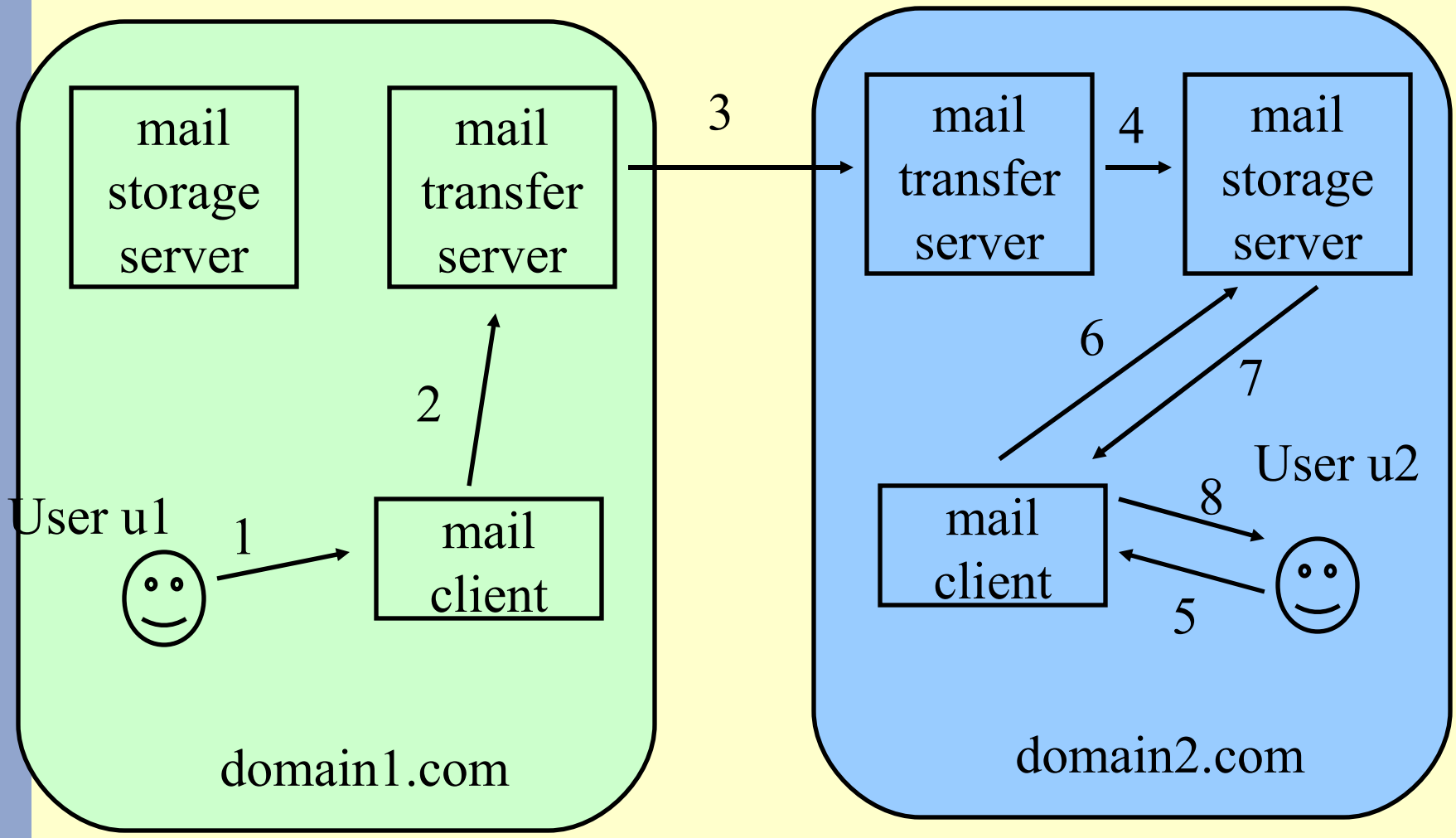
Administrator Countermeasures

- Preventive countermeasures:
  - deployment of additional protection: Firewalls, VPN's, …
  - patching weaknesses where possible: CERT advisories, Windows Update, …
- Detective countermeasures:
  - Intrusion Detection software or Fraud Detection software
  - Virus scanning
- Security solutions should be managed, supporting reactive countermeasures

Overview

- Introduction
- Key Concepts
  - Threats, Vulnerabilities, Countermeasures
  - Example
- Microsoft's Threat Modeling Process
- Conclusion

Simplified e-mail system



Assets

- E-mail messages
  - header
  - body
- Address book / contact information
- Client and Server machines
  - Storage space
  - Computational resources
  - Mail delivery service
  - Infrastructural software (OS,…)
- Network infrastructure
- …

Threats

- E-mail message
  - Unauthorized reading of message body
    - Define what is “authorized”!
  - Tampering with message
    - In transit
    - In storage
  - E-mail spoofing (tampering with the from: field)
  - Repudiation
    - Of sending
    - Of receipt
  - …

Threats

- Client and Server machines
  - Denial of service
    - E.g. Inbox storage space
  - Elevation of privilege
    - Server is a “trusted software layer”, making a limited functionality (sending/receiving mail) available to clients
    - If you can break the server out of this limited functionality (e.g. because of bugs), you can attack the server machine
  - E-mail viruses
    - E.g. through executable attachments
  - Unauthorized use of mail delivery service
    - E.g. Spam e-mail
  - …

Threats

- Not all “undesirable behavior” can easily be related to assets:
  - Detecting when somebody reads his mail
    - Asset = “privacy of the reader”?
  - …

Vulnerabilities

- Requirements: Security was not a concern in the original design of Internet e-mail
  - As a consequence, plain e-mail system is vulnerable to **all** identified threats
  - Countermeasures have been designed and integrated over the past decades
- Construction:
  - Implementation bugs in all e-mail components have been exploited
  - Sometimes amplified because of vulnerabilities in OS
- Operation:
  - Insecure configuration of e-mail: open mail relays, sendmail debug mode, …

Possible Countermeasures

- Public key encryption and signing of e-mail, counters:
  - e-mail spoofing
  - tampering / reading messages in transit
  - repudiation of sending
- Password based authentication and access control
  - Counters tampering / reading messages in storage
- Sandboxing of attachments
  - Counters virus-spreading
- Code review or static analysis of server code
  - Counters elevation-of-privilege on server
- …

Vulnerabilities in Countermeasures

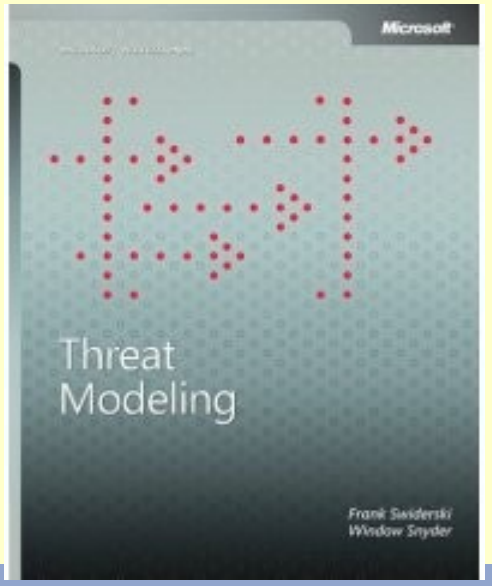
- Weak encryption algorithms
- Predictable generation of encryption keys
- Guessable passwords
- False negatives in static analysis for bugs
- …

Overview

- Introduction
- Key Concepts
  - Threats, Vulnerabilities, Countermeasures
  - Example
- Microsoft's Threat Modeling Process
- Conclusion

Introduction

- As part of it's Secure Development Life Cycle, Microsoft has defined a threat modeling activity
  - Supported by documentation and tools
- Goal for the rest of this session:
  - Discuss the structure of this Threat Modeling process
  - Illustrate it with the tool



Overall Structure

- Understand the adversary's view
  - Entry points
  - Assets
  - Trust Levels
- Characterize the security of the system
  - Use Scenarios
  - Assumptions and dependencies
  - Model the system
- Determine threats
  - Identify threats
  - Analyze threats

Understand the adversary's view

- Entry points:
  - any location where data or control flow crosses the system's boundary
  - E.g. sockets, RPC interfaces, GUI elements, …
- Assets:
  - Anything that needs protection
    - Information, resources, functionality
- Trust levels:
  - Categorization of possible threat agents according to "power"

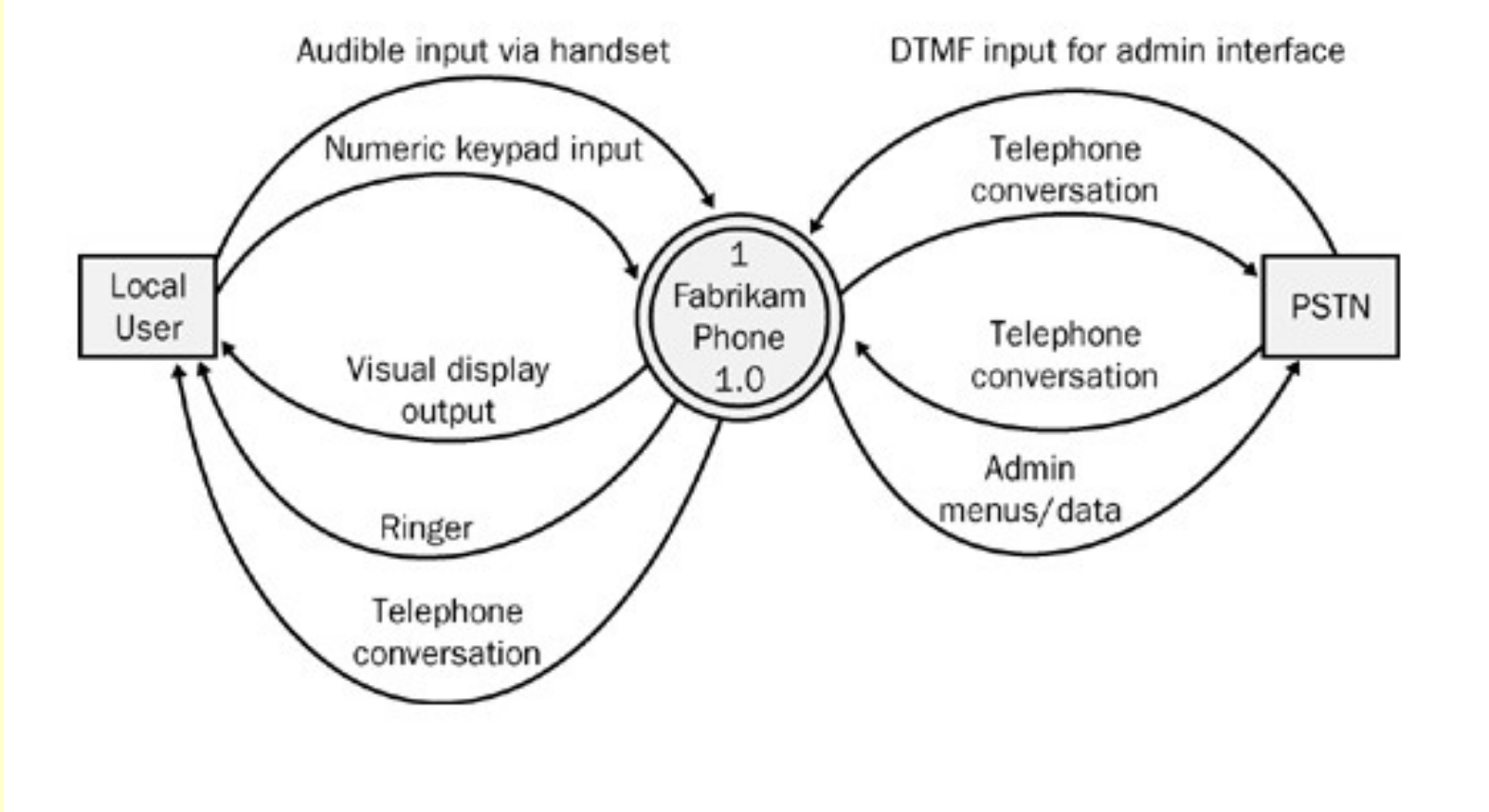
Characterize the security of the system

- Define use scenarios
  - Define how the system will be used, and how it won't be used
    - Bound the threat modeling discussion
- Identify assumptions and dependencies
  - External dependencies: requirements on systems outside the system being modeled
  - External security notes: security relevant information to users that interface with the system
  - Internal security notes: information for the reader of the threat model
  - Implementation assumptions: Assumptions under which the current threat model was made

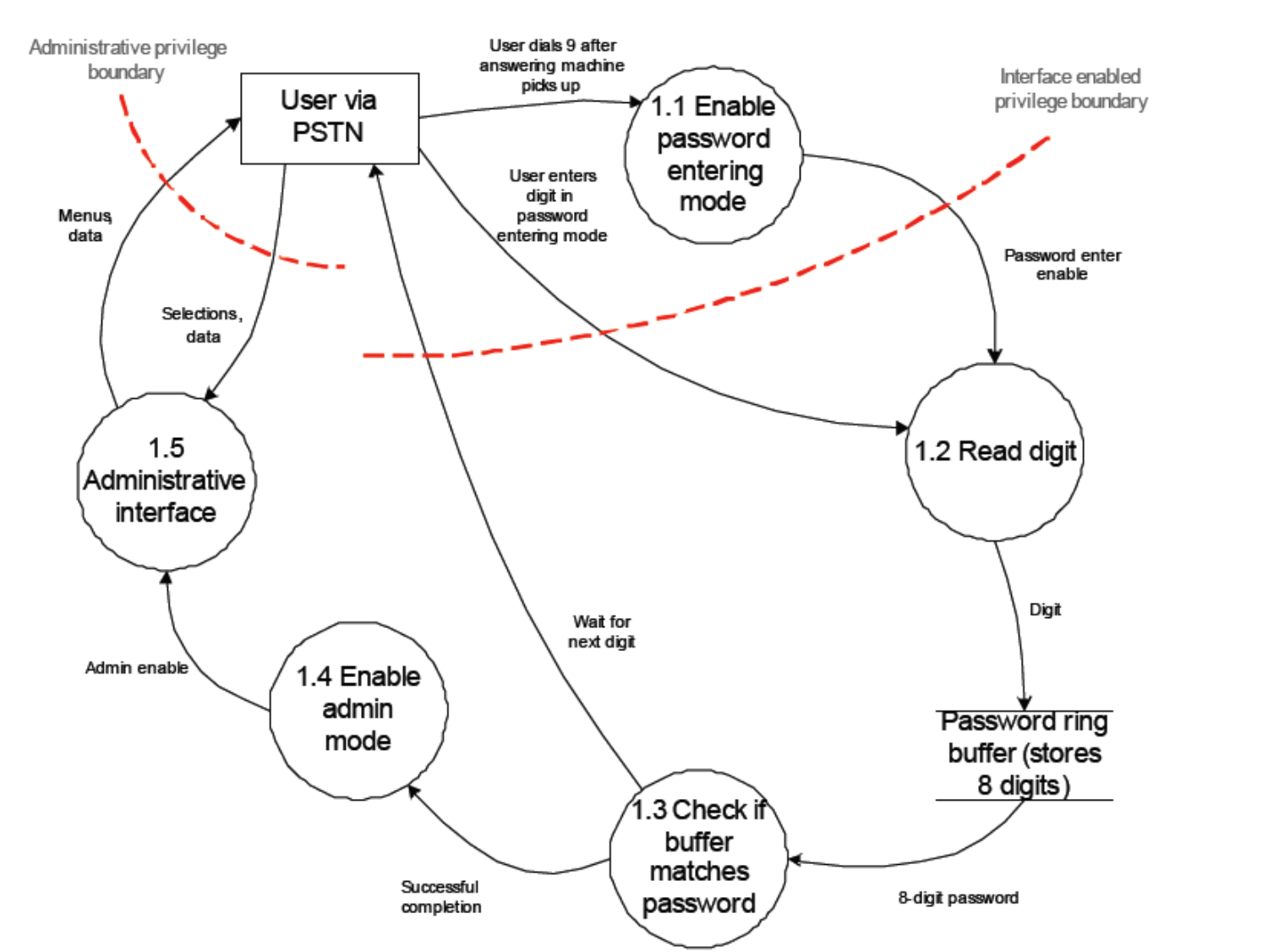
Characterize the security of the system

- Model the system
  - Typically modeled using dataflow diagrams
    - External entities
    - Processes
    - Data stores
    - Data flow
    - Privilege boundaries

Example DFD


Audible input via handset
DTMF input for admin interface
Numeric keypad input
Telephone conversation
Local User
1 Fabrikam Phone 1.0
PSTN
Visual display output
Telephone conversation
Admin menus/data
Ringer
Telephone conversation

Example DFD


Administrative privilege boundary
User via PSTN
User dials 9 after answering machine picks up
1.1 Enable password entering mode
Interface enabled privilege boundary
User enters digit in password entering mode
Menus, data
Selections, data
Password enter enable
1.5 Administrative interface
1.2 Read digit
Digit
Wait for next digit
Admin enable
1.4 Enable admin mode
Password ring buffer (stores 8 digits)
1.3 Check if buffer matches password
Successful completion
8-digit password

Determine threats

- Determine threats: elicit and categorize threats using the STRIDE categories:
  - Spoofing
  - Tampering
  - Repudiation
  - Information leakage
  - Denial-of-service
  - Elevation of Privilege
- Analyze threats
  - Threat trees decompose threats
  - Risk rating for vulnerabilities, e.g using DREAD

Overview

- Introduction
- Key Concepts
  - Threats, Vulnerabilities, Countermeasures
  - Example
- Microsoft's Threat Modeling Process
- Conclusion

Conclusion

- Threat modeling is an activity to be performed in the early phases of the software life cycle
  - In order to understand the “threat profile” of the software
  - In order to select countermeasures in an informed way
- Microsoft places Threat Modeling in the top 2 of most important security related activities
  - Other one is static analysis for implementation vulnerabilities