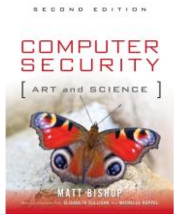
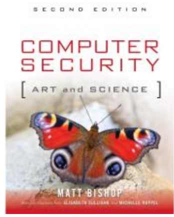


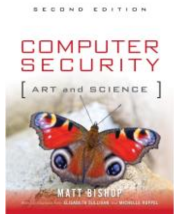
Availability Policies

Chapter 7



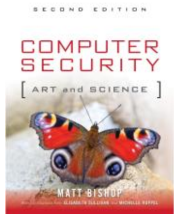
Outline

- Goals
- Deadlock
- Denial of service
  - Constraint-based model
  - State-based model
- Networks and flooding
- Amplification attacks



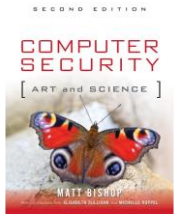
Goals

- Ensure a resource can be accessed in a timely fashion
  - Called “quality of service”
  - “Timely fashion” depends on nature of resource, the goals of using it
- Closely related to safety and liveness
  - Safety: resource does not perform correctly the functions that client is expecting
  - Liveness: resource cannot be accessed



Key Difference

- Mechanisms to support availability in general
  - Lack of availability assumes average case, follows a statistical model
- Mechanisms to support availability as security requirement
  - Lack of availability assumes worst case, adversary deliberately makes resource unavailable
  - Failures are non-random, may not conform to any useful statistical model



Deadlock

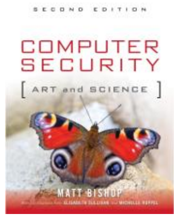
- A state in which some set of processes block each waiting for another process in set to take come action
  - *Mutual exclusion*: resource not shared
  - *Hold and wait*: process must hold resource and block, waiting other needed resources to become available
  - *No preemption*: resource being held cannot be released
  - *Circular wait*: set of entities holding resources such that each process waiting for another process in set to release resources
- Usually not due to an attack

Approaches to Solving Deadlocks

- *Prevention*: prevent 1 of the 4 conditions from holding
  - Do not acquire resources until all needed ones are available
  - When needing a new resource, release all held
- *Avoidance*: ensure process stays in state where deadlock cannot occur
  - *Safe state*: deadlock can not occur
  - *Unsafe state*: may lead to state in which deadlock can occur
- *Detection*: allow deadlocks to occur, but detect and recover

Denial of Service

- Occurs when a group of authorized users of a service make that service unavailable to a (disjoint) group of authorized users for a period of time exceeding a defined maximum waiting time
  - First “group of authorized users” here is group of users with access to service, whether or not the security policy grants them access
  - Often abbreviated “DoS” or “DOS”
- Assumes that, in the absence of other processes, there are enough resources
  - Otherwise problem is not solvable unless more resources created
  - Inadequate resources is another type of problem

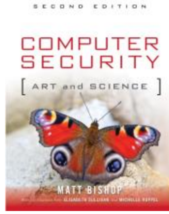


Components of DoS Model

- *Waiting time policy*: controls the time between a process requesting a resource and being allocated that resource
  - Denial of service occurs when this waiting time exceeded
  - Amount of time depends on environment, goals
- *User agreement*: establishes constraints that process must meet in order to access resource
  - Here, “user” means a process
  - These ensure a process will receive service within the waiting time

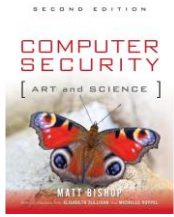
Constraint-Based Model (Yu-Gligor)

- Framed in terms of users accessing a server for some services
- *User agreement*: describes properties that users of servers must meet
- *Finite waiting time policy*: ensures no user is excluded from using resource



User Agreement

- Set of constraints designed to prevent denial of service
- S_{seq} sequence of all possible invocations of a service
- U_{seq} set of sequences of all possible invocations by a user
- $U_{li,seq} \subseteq U_{seq}$ that user U_i can invoke
    - C set of operations U_i can perform to consume service
    - P set of operations to produce service user U_i consumes
    - $p < c$ means operation $p \in P$ must precede operation $c \in C$
    - A_i set of operations allowed for user U_i
    - R_i set of relations between every pair of allowed operations for U_i



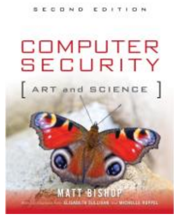
Example

Mutually exclusive resource

- $C = \{ \mathit{acquire} \}$
- $P = \{ \mathit{release} \}$
- For p_1, p_2, $A_i = \{ \mathit{acquire}_i, \mathit{release}_i \}$ for $i = 1, 2$
- For p_1, p_2, $R_i = \{ (\mathit{acquire}_i < \mathit{release}_i) \}$ for $i = 1, 2$

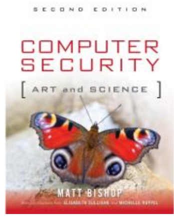
Sequences of Operations

- $U_i(k)$ initial subsequence of U_i of length k
  - $n_o(U_i(k))$ number of times operation o occurs in $U_i(k)$
- $U_i(k)$ safe if the following 2 conditions hold:
  - if $o \in U_{i,seq}$, then $o \in A_i$; and
    - That is, if U_i executes o, it must be an allowed operation for U_i
  - for all k, if $(o < o') \in R_i$, then $n_o(U_i(k)) \geq n_{o'}(U_i(k))$
    - That is, if one operation precedes another, the first one must occur more times than the second



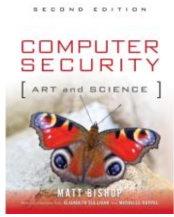
Resources of Services

- $s \in S_{seq}$ possible sequence of invocations of services
- s blocks on condition c
  - May be waiting for service to become available, or processing some response, etc.
- $o_i^*(c)$ represents operation o_i blocked, waiting for c to become true
  - When execution results, $o_i(c)$ represents operation
  - Note that when c becomes true, $o_i^*(c)$ may not resume immediately



Resources of Services

- $s(0)$ initial subsequence of s up to operation $o_i^*(c)$
- $s(k)$ subsequence of operations between k-1st, kth time c becomes true after $o_i^*(c)$
- $o_i^*(c) \rightarrow^{s(k)} o_i(c)$: o_i blocks waiting on c at end of $s(0)$, resumes operation at end of $s(k)$
- S_{seq} *live* if for every $o_i^*(c)$ there is a set of subsequences $s(0), \ldots, s(k)$ such that it is initial subsequence of some $s \in S_{seq}$ and $o_i^*(c) \rightarrow^{s(k)} o_i(c)$



Example

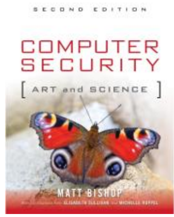
- Mutually exclusive resource; consider sequence

$$(acquire_i, release_i, acquire_i, acquire_i, release_i)$$

  with $acquire_i$, $release_i \in A_i$, $(acquire_i, release_i) \in R_i$; $o = acquire_i$, $o' = release_i$
- $U_i(1) = (acquire_i\ ) \Rightarrow n_o(U_i(1)) = 1, n_{o'}(U_i(1)) = 0$
- $U_i(2) = (acquire_i, release_i\ ) \Rightarrow n_o(U_i(2)) = 1, n_{o'}(U_i(2)) = 1$
- $U_i(3) = (acquire_i, release_i, acquire_i) \Rightarrow n_o(U_i(3)) = 2, n_{o'}(U_i(3)) = 1$
- $U_i(4) = (acquire_i, release_i, acquire_i, acquire_i) \Rightarrow$
  $n_o(U_i(4)) = 3, n_{o'}(U_i(4)) = 1$
- $U_i(5) = (acquire_i, release_i, acquire_i, acquire_i, release_i) \Rightarrow$
  $n_o(U_i(5)) = 3, n_{o'}(U_i(5)) = 2$
- As $n_o(U_i(k)) \geq n_{o'}(U_i(k))$ for $k = 1, ..., 5$, the sequence is safe

Example (*con't*)

- Let c be true whenever resource can be released
  - That is, initially and whenever a $release_i$ operation is performed
- Consider sequence: ($acquire_1$, $acquire_2^*(c)$, $release_1$, $release_2$, ... , $acquire_k$, $acquire_{k+1}(c)$, $release_k$, $release_{k+1}$, ...)
- For all $k \geq 1$, $acquire_i^*(c) \rightarrow^{s(1)} acquire_{k+1}(c)$, so this is live sequence
  - Here, $acquire_{k+1}(c)$ occurs between $release_k$ and $release_{k+1}$



Expressing User Agreements

- Use temporal logics
- Symbols
  - $\Box$: henceforth (the predicate is true and will remain true)
  - $\Diamond$: eventually (the predicate is either true now, or will become true in the future)
  - $\leadsto$: will lead to (if the first part is true, the second part will eventually become true); so $A \leadsto B$ is shorthand for $A \Rightarrow \Diamond B$

Example

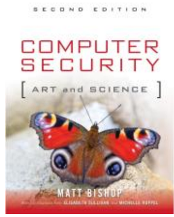
- Acquiring and releasing mutually exclusive resource type
- User agreement: once a process is blocked on an *acquire* operation, enough *release* operations will release enough resources of that type to allow blocked process to proceed

service resource_allocator

User agreement

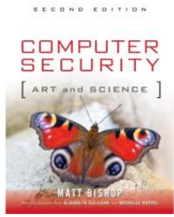
$$in(acquire) \rightsquigarrow ((\Box\Diamond(\#active\_release > 0) \vee (free \geq acquire.n))$$

- When a process issues an *acquire* request, at some later time at least 1 *release* operation occurs, and enough resources will be freed for the requesting process to acquire the needed resources



Finite Waiting Time Policy

- *Fairness policy*: prevents starvation; ensures process using a resource will not block indefinitely if given the opportunity to progress
- *Simultaneity policy*: ensures progress; provides opportunities process needs to use resource
- *User agreement*: see earlier
- If these three hold, no process will wait an indefinite time before accessing and using the resource



Example

- Continuing example ... these and above user agreement ensure no indefinite blocking

sharing policies

fairness

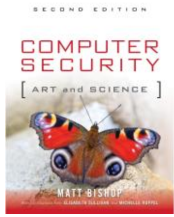
$$(at(acquire) \wedge \Box\Diamond((free \geq acquire.n) \wedge (\#active = 0))) \leadsto after(acquire)$$

$$(at(release) \wedge \Box\Diamond(\#active = 0)) \leadsto after(release)$$

simultaneity

$$(in(acquire) \wedge (\Box\Diamond(free \geq acquire.n)) \wedge (\Box\Diamond(\#active = 0))) \leadsto ((free \geq acquire.n) \wedge (\#active = 0))$$

$$(in(release) \wedge \Box\Diamond(\#active\_release > 0)) \leadsto (free \geq acquire.n)$$



Service Specification

- Interface operations
- Private operations not available outside service
- Resource constraints
- Concurrency constraints
- Finite waiting time policy

Example:

- Interface operations of the resource allocation/deallocation example

interface operations

acquire(*n*: *units*)

exception conditions: $quota[id] < own[id] + n$

effects: $free' = free - n$

$own[id]' = own[id] + n$

release(*n*: *units*)

exception conditions: $n > own[id]$

effects: $free' = free + n$

$own[id]' = own[id] - n$

Example (*con't*)

- Resource constrains of the resource allocation/deallocation example

resource constraints

1. $\Box((free \geq 0) \land (free \leq size))$
2. $(\forall\ id)\ [\Box(own[id] \geq 0) \land (own[id] \leq quota[id]))]$
3. $(free = N) \Rightarrow ((free = N)\ \text{UNTIL}\ (after(acquire) \lor after(release)))$
4. $(\forall\ id)\ [\ (own[id] = M) \Rightarrow ((own[id] = M)\ \text{UNTIL}\ (after(acquire) \lor after(release)))]$

Example (*con't*)

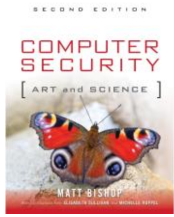
- Concurrency constraints of the resource allocation/deallocation example

concurrency constraints

1. $\square(\#active \le 1)$
2. $(\#active = 1) \leadsto (\#active = 1)$

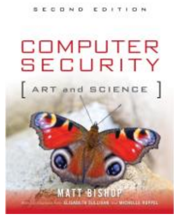
Denial of Service

- Service specification policies, user agreements prevent denial of service *if enforced*
- These do *not* prevent a long wait time; they simply ensure the wait time is finite



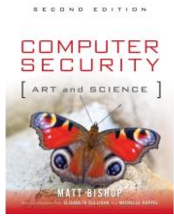
State-Based Model (Millen)

- Unlike constraint-based model, allows a maximum waiting time to be specified
- Based on resource allocation system, denial of service base that enforces its policies



Resource Allocation System Model

- *R* set of resource types
- For each $r \in R$, number of resource units (capacity, $c(r)$) is constant; a process can hold a unit for a maximum holding time $m(r)$
- *P* set of processes
- For each $p \in P$, state is *running* or *sleeping*
  - When allocated a resource, process is running
  - Multiple process can be in running state simultaneously
  - Each *p* has upper bound it can be in running state before being interrupted, if only by CPU quantum *q*
  - Example: if CPU considered a resource, $m(\text{CPU}) = q$

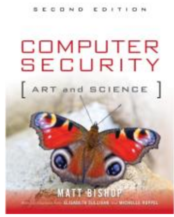


Allocation Matrix

- Rows represent processes; columns represent resources
  - $A: P \times R \rightarrow \mathbb{N}$ is matrix
  - For $p \in P$, $r \in R$, $A_p(r)$ is number of resource units of type r acquired by p
  - As at most c(r) of resource type r exist, at most that many can be allocated at any time

R1: The system cannot allocate more instances of a resource type than it has:

$$(\forall r \in R)[\textstyle\sum_{p \in P} A_p(r) \leq c(r)]$$

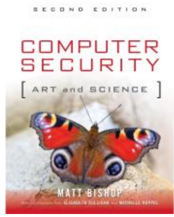


More About Resources

- $T: P \rightarrow \mathbb{N}$ is system time when resource assignment was last changed
    - Think of it as a time vector, each element belonging to one process
- $Q^S: P \times R \rightarrow \mathbb{N}$ is matrix of required resources for each process, *not including the resources it already holds*
    - So $Q^S_p(r)$ means the number of units of resource type r that process p may need to complete
- $Q^T: P \times R \rightarrow \mathbb{N}$ is matrix of how much longer each process p needs the units of resource r
- Predicates *running*(p) true if p is in running state; *asleep*(p) true otherwise

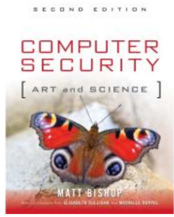
R2: A currently running process must not require additional resources to run

$$running(p) \Rightarrow (\forall r \in R)[Q^S_p(r) = 0]$$



States, State Transitions

- Current state of system is (A, T, Q^S, Q^T)
- State transition $(A, T, Q^S, Q^T) \rightarrow (A', T', Q^{S}{}', Q^{T}{}')$
  - We only care about treansitions due to allocation, deallocation of resources
- Three relevant types of transitions
  - *Deactivation transition*: *running*(*p*) → *asleep*′(*p*); process stops execution
  - *Activation transition*: *asleep*(*p*) → *running*′(*p*); process starts or resumes execution
  - *Reallocation transition*: transition in which *p* has resource allocation changed; can only occur when *asleep*(*p*)



Constraints

R3: Resource allocation does not affect allocations of a running process:

$$(running(p) \land running'(p)) \Rightarrow (A_p' = A_p)$$

R4: $T(p)$ changes only when resource allocation of p changes:

$$(A_p'(\text{CPU}) = A_p(\text{CPU})) \Rightarrow (T'(p) = T(p))$$

R5: Updates in time vector increase value of element being updated:

$$(A_p'(\text{CPU}) \neq A_p(\text{CPU})) => (T'(p) > T(p))$$

Constraints

R6: When p reallocated resources, allocation matrix updated before p resumes execution:

$$asleep(p) \Rightarrow Q^S{}_p' = Q^S{}_p + A_p - A_p'$$

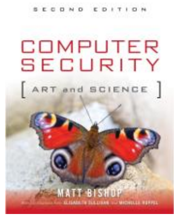
R7: When a process is not running, the time it needs resources does not change:

$$asleep(p) \Rightarrow Q^T{}_p' = Q^T{}_p$$

R8: when a process ceases to execute, the only resource it *must* surrender is the CPU:

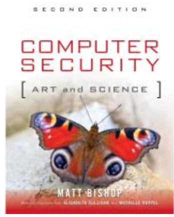
$$(running(p) \land asleep'(p)) \Rightarrow A_p'(r) = A_p(r)-1 \quad \text{if } r = \text{CPU}$$

$$(running(p) \land asleep'(p)) \Rightarrow A_p'(r) = A_p(r) \quad \text{otherwise}$$



Resource Allocation System

- A system in a state (A, T, Q^S, Q^T) such that:
  - State satisfies constraints R1, R2
  - All state transitions constrained to meet R3-R8



Denial of Service Protection Base (DPB)

- A mechanism that is tamperproof, cannot be prevented from operating, and guarantees authorized access to resources it controls
- Four parts:
  - Resource allocation system (see earlier)
  - Resource monitor
  - Waiting time policy
  - User agreement (see earlier; constraints apply to changes in allocation when process transitions from *running*(*p*) to *asleep*(*p*)

Resource Monitor

- Controls allocation, deallocation of resources and the timing
- $Q^S{}_p$ is *feasible* if $(\forall i)[Q^S{}_p(r_i) + A_p(r_i) \leq c(r_i)] \land Q^S{}_p(\text{CPU}) \leq 1$
  - If the total number of resources it will be allocated will always be no more than the capacity of that resource, and no more than 1 CPU is requested
- T_p is *feasible* if $(\forall i)[T_p(r_i) \leq max(r_i)]$
  - Here, $max(r_i)$ max time a process must wait for its needed allocation of units of resource type i

Waiting Time Policy

- Let σ = (A, T, Q^S, Q^T)
- Example finite waiting time policy:

$$(\forall p, \sigma)(\exists \sigma')[running'(p) \land (T'(p) \geq T(p))]$$

  - For every process and state, there is a future state in which p is executing and has been allocated resources
- Example maximum waiting time policy:

$$(\exists M)(\forall p, \sigma)(\exists \sigma')[running'(p) \land (0 < T'(p) - T(p) \leq M)]$$

  - There is an upper bound M to how long it takes every process to reach a future state in which it is executing and has been allocated resources

Two Additional Constraints

In addition to all these, a DPB must satisfy these constraints:

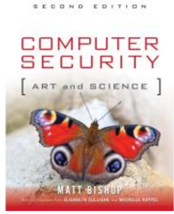
1. Each process satisfying user agreement constraints will progress in a way that satisfies the waiting time policy
2. No resource other than the CPU is deallocated from a process unless that resource is no longer needed

$$(\forall i)[r_i \neq \text{CPU} \wedge A_p(r_i) \neq 0 \wedge A_p'(r_i) = 0] \Rightarrow Q^T{}_p(r_i) = 0$$

Example: DPB

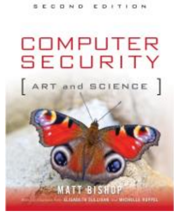
- Assume system has 1 CPU
- Assume maximum waiting time policy in place
- 3 parts to user agreement:
  - Q^S_p, T_p are *feasible*
  - Process in running state executes for a minimum amount of time before it transitions to a non-running state
  - If process requires resource type, and enters a non-running state, the time it needs the resource for is decreased by the amount of time it was in the previous running state; that is,

$$Q^T_p \neq \mathbf{0} \land running(p) \land asleep'(p) \Rightarrow (\forall r \in R)[Q^T_p(r) \leq max(0, max_r\, Q^T_p(r) - (T'(p) - T(p)))]$$



Example: System

- n processes, round robin scheduler with quantum q
- Initially no process has any resources
- Resource monitor selects process p to give resources to
  - p executes until $Q^T_p = \mathbf{0}$ or monitor concludes Q^S_p or T_p is not feasible
- Goal: show there will be no denial of service in this system because
  a) no resource r_i is deallocated from p for which Q^S_p is feasible until $Q^T_p = 0$; and
  b) there is a maximum time for each round robin cycle

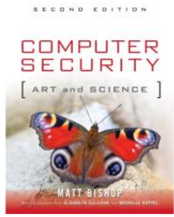


Claim (a)

- Before p selected, no process has any resources allocated to it
  - So next process with Q^S_p and T_p feasible is selected
  - It runs until it enters the *asleep* state or q, whichever is shorter
  - If in *asleep* state, process is done
  - If q, monitor gives p another quantum of running time; this repeats until $Q^T_p = 0$, and then p needs no more resources
- Let $m(r)$ be maximum time any process will hold resources of type r
  - Let $M(r) = max_r\, m(r)$
- As Q^S_p and T_p feasible, M upper bound for all elements of Q^T_p
  - $d = min(q$, minimum time before p transitions to *asleep* state); exists because a process in running state executes for a minimum amount of time before it transitions to a non-running state

Claim (a) (*con't*)

- As Q^S_p and T_p feasible, M upper bound for all elements of Q^T_p
- $d = min(q$, minimum time before p transitions to *asleep* state)
  - Exists because a process in running state executes for a minimum amount of time before it transitions to a non-running state
- At end of each quantum, $m'(r) = m(r) - d$
  - By third part of user agreement
- So after $floor(M/d + 1)$ quanta, $Q^T_p = \mathbf{0}$
  - So no resources deallocated until $(\forall i)\ Q^T_p(r_i) = 0$

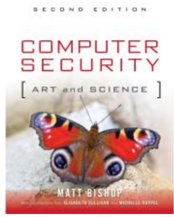


Claim (b)

- t_a is time between resource monitor beginning cycle and when it has allocated required resources to *p*
- Resource monitor then allocates CPU resource to *p*; call this time t_{CPU}
  - Done between each quantum
- When *p* completes, all its resources deallocated; this takes time t_d
- As $Q^S{}_p$ and T_p feasible, time needed to run *p*, including time to deallocate all resources, is:

$$t_a + \mathit{floor}(M/d + 1)(q + t_{\text{CPU}}) + t_d$$

- So for *n* processes, maximum time cycle will take is *n* times this
- Thus, there is a maximum time for each round robin cycle



Availability and Network Flooding

- Access over Internet must be unimpeded
  - Context: flooding attacks, in which attackers try to overwhelm system resources
- If many sources flood a target, it’s a *distributed denial of service attack*

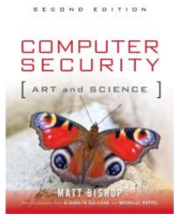
TCP 3-Way Handshake and Availability

source $\xrightarrow{\text{SYN}(s)}$ destination

source $\xleftarrow{\text{SYN}(t)\text{ACK}(s+1)}$ destination

source $\xrightarrow{\text{ACK}(t+1)}$ destination

- Normal three-way handshake to initiate connection
- Suppose source never sends third message (the last ACK)
  - Destination holds information about pending connection for a period of time before the space is released

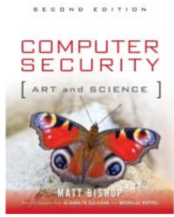


Analysis

- Consumption of bandwidth
  - If flooding overwhelms capacity of physical network medium, SYNs from legitimate handshake attempts may not be able to reach the target
- Absorption of resources on destination host
  - Flooding fills up memory space for pending connections, causing SYNs from legitimate handshake attempts to be discarded
- In terms of the models:
  - Waiting time is the time that destination waits for ACK from source
  - Fairness policy must assure host waiting for ACK (resource) will receive (acquire) it

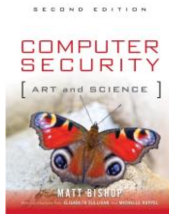
Analysis in Terms of Model

- Waiting time is the time that destination waits for ACK from source
- Fairness policy must assure host waiting for ACK (resource) will receive (acquire) it
  - But goal of attack is to make sure it never arrives
- Yu-Gligor model: finite wait time does not hold
  - So model says denial of service can occur
- Millen model: T_p(ACK) > *max*(ACK)
  - *max*(ACK) is the time-out period for pending connections
  - So model says denial of service can occur



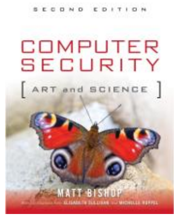
Countermeasures

- Focus on ensuring resources needed for legitimate handshakes to complete are available
  - So every legitimate client gets access to server
- First approach: manipulate opening of connection at end point
  - If focus is to ensure connection attempts will succeed at some time, focus is really on waiting time
  - Otherwise, focus is on user agreement
- Second approach: control which packets, or rate at which packets, sent to destination
  - Focus is on implicit user agreements



Intermediate Systems

- Approach is to reduce consumption of resources on destination by diverting or eliminating illegitimate traffic so only legitimate traffic reaches destination
  - Done at infrastructure level
- Example: Cisco routers try to establish connection with source (TCP intercept mode)
  - On success, router does same with intended destination, merges the two
  - On failure, short time-out protects router resources and target never sees flood



Track Connection Status

- Use network monitor to track status of handshake
- Example: *synkill* monitors traffic on network
  - Classifies IP addresses as not flooding (good), flooding (bad), unknown (new)
  - Checks IP address of SYN
    - If good, packet ignored
    - If bad, send RST to destination; ends handshake, releasing resources
    - If new, look for ACK or RST from same source; if seen, change to good; if not seen, change to bad
  - Periodically discard stale good addresses

Intermediate Systems near Sources

- D-WARD relies on routers close to the sources to block attack
  - Reduces congestion in network without interfering with legitimate traffic
- Placed at gateways of possible sources to examine packets leaving (internal) network and going to Internet
- Deployed on systems in research lab for 4 months
  - First month: large number of false alerts
  - Tuning D-WARD parameters reduced this number

D-WARD: Observation Component

- Has set of legitimate internal addresses
- Gathers statistics on packets leaving network, discarding packets without legitimate addresses
- Tracks number of simultaneous connections to each remote destination
    - Unusually large number may indicate attack from this network
- Examines connections with large amount of outgoing traffic but little incoming (response) traffic
    - May indicate destination host is overwhelmed

D-WARD: Observation Component

- Also aggregates traffic statistics to each remote address
- Classifies flows as *attack*, *suspicious*, *normal*
  - *Normal*: statistics match legitimate traffic model
  - *Attack*: if not
- Once traffic classified as attack begins to match legitimate traffic model, indicates attack has ended, so flow reclassified as *suspicious*
  - If it stays suspicious for predetermined time, reclassified as *normal*

D-WARD: Rate-Limiting Component

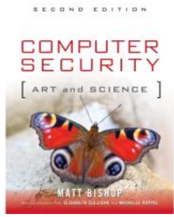
- When attack detected, this component limits amount of packets that can be sent
- This reduces volume of traffic going from this network to destination
- How it limits rate is based on D-WARD’s best guess of amount of traffic destination can handle
  - When flow reclassified as normal, D-WARD raises rate limit until sending rate is as before

D-WARD: Traffic-Policing Component

- Component obtains information from other 2 components
- Based on this, decides whether to drop packets
    - Packets for normal connections always forwarded
    - Packets for other flows may be forwarded provided doing so does not exceed rate limit associated with flow

Endpoint Protection

- Control how TCP state is stored
  - When SYN received, entry in queue of pending connections created
    - Remains until an ACK received or time-out
    - In first case, entry moved to different queue
    - In second case, entry made available for next SYN
  - In SYN flood, queue is always full
    - So, assure legitimate connections space in queue to some level of probability
    - Two approaches: SYN cookies or adaptive time-outs



SYN Cache

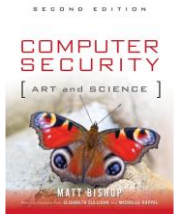
- Space allocated for each pending connection
  - But much less than for a full connection
- How it works on FreeBSD
  - On initialization, hash table (*syncache*) created
  - When SYN packet arrives, system generates hash from header and uses that to determine which bucket to store enough information to be able to send SYN/ACK on the pending connection (and does so)
    - If bucket full, oldest element dropped
  - If peer returns ACK, entry removed and connection created
  - If peer returns RST, entry removed
  - If no response, repeat fixed number of times; if no responses, remove entry

SYN Cookies

- Source keeps state
- How it works
    - When SYN arrives, generate number (*syncookie*) from header data and random data; use as ACK sequence number in SYN/ACK packet
        - Random data changes periodically
    - When reply ACK arrives, recompute syncookie from information in header
- FreeBSD uses this technique when pending connection cannot be inserted into syncache

Adaptive Time-Out

- Change time-out time as space available for pending connections decreases
- Example: modified SunOS kernel
  - Time-out period shortened from 75 to 15 sec
  - Formula for queueing pending connections changed:
    - Process allows up to *b* pending connections on port
    - *a* number of completed connections but awaiting process
    - *p* total number of pending connections
    - *c* tunable parameter
    - Whenever $a + p > cb$, drop current SYN message

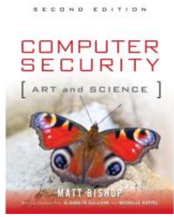


Other Flooding Attacks

- These use *reflectors* (typically, infrastructure systems) to augment traffic, creating flooding
  - Attacker need only send small amount of traffic; reflectors create the rest
  - Called *amplification attack*
- Hides origin of attack, which appears to come from reflectors

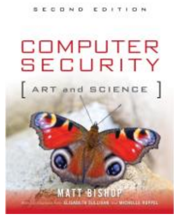
Smurf Attack

- Relies on router forwarding ICMP packets to all hosts on network
- Attacker sends ICMP packet to router with destination address set to broadcast address of network
- Router sends copy of packet to each host on network
  - If attacker sends steady stream of packets, has the effect of sending that stream to all hosts on network
- Example of an *amplification attack*



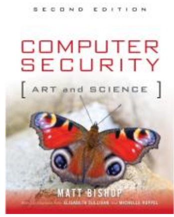
DNS Amplification Attack

- Uses DNS resolvers that are configured to accept queries from any host rather than only hosts on their own network
- Attacker sends packet with source address set to that of target
    - Packet has query that causes DNS resolver to send large amount of information to target
    - Example: zone transfer query is a small query, but typically sends large amount of data to target, typically in multiple packets, each larger than a query packet



Pulse Denial of Service Attack

- Like flooding, but packets sent in pulses
  - May only degrade target’s performance, but that may be enough of a denial of service
- Induces 3 anomalies in traffic to target
  - Ratio of incoming TCP packets to outgoing ACKs increases dramatically
    - Rate of incoming packets much higher than system can send ACKs
  - When attacker reduces number of packets to target, number of ACKS drop
  - Distribution of incoming packet interarrival time will be anomalous
- Vanguard detection scheme uses these 3 anomalies to detect pulse denial-of-service attack



Key Points

- Availability in security context deals with malicious denial of service
- Models of denial of service have waiting time policy and user agreement as key components
- Network denial-of-service attacks, and countermeasures, instantiate these models
- Amplification attacks usually hide origin of attacks, and enable flooding by an attacker that sends a relatively small number of packets