

Causes of Failure in Web Applications

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Abstract

This report investigates the causes and prevalence of failure in Web applications. Data was collected by surveying case studies of system failures and by examining incidents of website outages listed on technology websites such as CNET.com and eweek.com. These studies suggest that software failures and human error account for about 80% of failures. The report also contains an appendix that serves as a quick reference for common failures observed in Web applications. This appendix lists over 40 incidents of real-world site outages, outlining how these failures were detected, the estimated downtime, and the subsequent recovery action.

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Keywords: Web applications, causes of failure, fault chains, unplanned downtime.

1 Introduction

The Web serves as an integral part of the day-to-day operation of many organizations. Businesses often rely on the Web to attract clients, communicate with suppliers, and generate revenues. As a result, the cost of failed online transactions can be significant: a single hour of downtime could cost a retailer thousands of dollars in lost sales. For example, during the Thanksgiving holiday weekend in 2001, Amazon.com suffered a series of outages, which cost the retailer an estimated $25,000 per minute of downtime [1]. The true costs of downtime are much higher: lost or dissatisfied customers, damage to the company's reputation, possible impact on the company's stock price, and lost employee productivity [2].

This report investigates the causes of failure in Web applications, and looks into the prevalence of these failures. Data was collected by surveying case studies of system failures and by examining incidents of website outages listed on technology websites such as CNET.com and eweek.com. The report contains an appendix that serves as a quick reference for common failures observed in Web applications. This appendix lists over 40 incidents of real-world site outages, outlining how these failures were detected, the estimated downtime, and the subsequent recovery action. A summary of the findings in this report is given below:

- Software failures and human error account for about 80% of failures [3].
- The incidents of software failures on the Web suggest that a large number of non-malicious failures occur during routine maintenance, software upgrades and system integration. It is unclear whether these failures are mainly due to system complexity, inadequate testing and/or poor understanding of system dependencies. Site owners tend to be vague about the underlying cause of the failure.
- Other significant causes of software failure are system overload, resource exhaustion and complex fault-recovery routines.
- Site outages ranged from a few minutes to several weeks (see appendix). During this period, the site may be completely unavailable or experiencing intermittent outages. Prolonged downtime often occurs when multiple components are implicated in the failure (i.e. large fault-chains).
- Business research [4] shows that planned downtime accounts for at least 80% of all downtime while the balance of less than 20% is unplanned downtime. Planned downtime contributes to about 15% of unplanned downtime, for instance, when a backup takes longer than planned.

The remainder of this report is organized as follows. Section 2 discusses the causes and manifestation of failures in Internet Services. Section 3 describes incidents where multiple components are implicated in the failure (i.e., large fault-chains). Section 4 examines the prevalence of failures. Section 5 compares planned downtime to unplanned downtime. Section 6 concludes the report. The appendix lists examples of real-world site outages.

2 Causes and Manifestations of Failures

Websites experience permanent, intermittent or transient failures, which may affect the entire site or be restricted to parts of the site. Permanent failures persist until the system the system is repaired, e.g., a disconnected network cable. Transient failures eventually disappear without any apparent intervention. Intermittent failures are transient failures that recur occasionally, e.g., when the system is overloaded. In this section, we explore the common causes of failures in Web applications and the manifestation of these failures.

2.1 Causes of Failure

We classified the causes of failures in Web applications into four categories namely: software failures, operator error, hardware and environmental failures, and security violations. We focus on non-malicious failures but list some failures that occur due to security violations for the sake of completeness.

The appendix gives a more detailed description the causes of failure and lists examples of outages. The categories listed in the appendix are not mutually exclusive and some failure modes may overlap several categories. Vijayaraghavan's taxonomy of e-commerce failures [5] is another comprehensive resource that outlines the causes of failure in e-commerce systems. This taxonomy lists test cases for a shopping cart application.

2.1.1 Software Failures

The incidents of software failures on the Web suggest that a large number of non-malicious failures occur during routine maintenance, software upgrades and system integration. It is unclear whether these failures are mainly due to system complexity, inadequate testing and/or poor understanding of system dependencies since site owners tend to be vague about the underlying cause of the failure.

Other significant causes of software failure are system overload, resource exhaustion and complex fault-recovery routines. Table 1 highlights examples of software failures.

Failure trigger	Examples	Real-world Incident
Resource exhaustion	• Memory leaks • Thread pool exhausted leading to slow or unresponsive server • Resource intensive processes cause server requests to timeout • Fast-growing log files consume disk space and cause server to crash	Zopewiki.org experiences memory leak in July 2004. Cause is unknown and the workaround is to reboot the server daily. http://zopewiki.org/ZopeWikiNews
Computational/logic errors	• Reference non-existent table in database • Pricing errors • Use of deallocated memory • Corrupt pointers • Synchronization errors, e.g., race conditions, deadlocks, starvation	Pricing error on Amazon's UK site lists iPaq H1910 Pocket PC for under $12 instead of regular retail price of $449 resulting in abnormally high sales in March 2003 http://news.com.com/2100-1017_3-993246.html
System Overload	• System overload can lead to resource contention and unanticipated interactions between other software processes running on the same machine, e.g., synchronization errors such as race conditions	Comair airlines cancels over 1,000 flights on Christmas Day 2004 when its computer systems for reservations crashed after severe weather caused a surge in crew flight re-assignments that knocked out its computer reservations system http://www.internetnews.com/bus-news/article.php/3451981
Recovery code	• Fault-recovery routines may be complex and not well tested.	A bank in Denmark experiences outage due to errors in database recovery routines following replacement of defective disk in April 2003 http://www.eweek.com/article2/0,1759,1008687,00.asp
Failed software upgrade	• Failure to back up the web-store before upgrade • Files upgraded successfully but did not go "live" after upgrade (failed deployment). • Upgrades performed without checking inter-compatibility between existing or newer software processes • Software upgrades sometimes sets all options to 'default' automatically after the installation is complete • Integration errors/Third party software failures	PayPal battled on-and-off service outages for about five days in October 2004 after upgrading site. They blamed glitches in the software update and waived customer fees for a day http://www.eweek.com/article2/0,1759,1684427,00.asp

Table 1: Examples of software failures

2.1.2 Human/Operator Errors

We classified operator errors into three categories: configuration errors, procedural errors and miscellaneous accidents. Configuration errors occur when operators define incorrect settings for system parameters, e.g., specifying an insufficient number threads to service user requests to the web server. Procedural errors occur when the operator either omits an action or executes an incorrect action during system maintenance. Table 2 describes examples of operator errors.

Failure trigger	Examples	Real-world Incident
Configuration errors	• System reset to default configuration by mistake • Accidentally corrupt configuration file • Omit necessary services from startup script	Incorrect configuration change in January 2001 to the routers on the edge of Microsoft's DNS network disrupts Microsoft.com, MSN.com, MSNBC.com, Hotmail.com and Encarta.com. http://www.internetnews.com/xSP/article.php/570171
Procedural errors	• Failure to back up database • Restored the wrong backup • Forgot to restart web server • Deleted files by mistake • Incorrect input, typos • Forgot to prune logs (disk fills up)	University of Michigan's ICPSR web server goes down in July 2002 when web logs grew too large due to a significant increase in traffic. http://www.icpsr.umich.edu/org/policies/webouts-2002.html
Miscellaneous accidents	• Equipment trauma caused by drop or fall • Accidentally disconnect power supply	Anne Lear [6] reports eBay incident where electrician came in to audit power usage and on his way out accidentally knocked out a plug.

Table 2: Examples of operator errors

2.1.3 Hardware and Environmental Failures

Hardware failures can occur for several reasons, e.g., wear and tear of mechanical parts, design flaws, loose wiring. Table 3 gives of hardware and environmental failures.

Failure trigger	Examples	Real-world Incident
Hardware failures	• Device driver failures • I/O errors, e.g., hard disk failures (see database media failures) • Memory parity errors • Network hardware failures	Hardware failure at the Wall Street Journal website causes 1hr outage in March 2004 http://news.com.com/2110-1025_3-5171623.html
Environmental failures	• Power outages • Overheating • High humidity • Natural disasters, e.g., hurricanes, floods	Loss of internal power distribution unit at youritdepot.com in August 2004 caused a air conditioning and temperature spikes to more than 113ºF. Overheating caused equipment failure and resulted in significant loss of internet traffic. http://www.youritdepot.com/index/nid/147

Table 3: Examples of hardware and environmental failures

2.1.4 Security Violations

This report focuses on non-malicious failures. However, we included examples of failures due to security violations for the sake of completeness. The list below highlights some of the common security violations that occur in websites:

- Password disclosures
- Denial of Service (DOS) attacks
- Worms and viruses
- Browser vulnerabilities
- Authentication failures
- Theft

2.2 Manifestation of Failure

The manifestation of the failure deals with the user-visible effects of a failure. Although the underlying causes of failure in Web applications are varied, the manifestation of the failure typically falls within the following broad categories:

- **Partial or entire site unavailable:** The user's request times out causing the user to receive error notices such as "404 file not found". This may be due to server crashes and hangs, network congestion or denial of service attacks.
- **System exceptions and access violations:** The executing process often terminates abruptly when a system exception is thrown. The error messages that arise vary depending on the error handling within the application that crashed, e.g., the system may display a very detailed access violation message with addresses and numbers, or nothing at all [7].
- **Incorrect results:** The executing process does not terminate but returns erroneous results, e.g., the site serves blank pages, returns wrong pages or wrong items. Since no exceptions are thrown, these failures are usually discovered only after a customer complains.
- **Data loss or corruption:** Data loss occurs when users are unable to access data from a previously functioning computer system, e.g., due to the accidental erasure of data. Corruption is probably the most difficult problem to diagnose. Corruption typically occurs from a boundary overwrite in memory. It is common to end up chasing the effect of memory corruption, rather than the problem that is causing it. The characteristics of corruption generally include random access violations or corrupt data [7].
- **Performance slowdowns:** Slowdowns may occur due to a variety of reasons, e.g., server overload, process hangs, deadlocks, resource exhaustion and network congestion.

3 Fault Chains

The fault chain refers to the series of component failures that led up to the user-visible failure. For instance, if a user-visible failure occurs after the failure of both the primary and backup servers, this failure has a fault-chain of length two. Large fault chains complicate recovery (see Table 4).

Fault-chains can be either *uncoupled* or *tightly-coupled*. *Uncoupled fault-chains* occur when independent failure events interact to produce user-visible failure. For instance, the primary server may fail due to resource exhaustion while the backup server fails independently due to hardware failure. On the other hand, *tightly-coupled fault-chains*, e.g., correlated or cascading failure, occur when failure events are tightly connected, for instance, a power outage causes air conditioning to fail resulting in equipment failure due to overheating.

The prevalence of large fault-chains varies from system to system. Gray [8] found that 60% of failures had fault chains of length two. This is because the Tandem system is single-fault tolerant so the second fault usually results in a user-visible failure. He also found that 20% of the failures had lengths of three or more. These failures chains were largely due to relatively high human error rates when invoking recovery procedures and complex recovery software that was not well tested.

Oppenheimer et al [9] found few failures with a failure chain of three or more in their study of failures in Internet services. Amir and Wool [10] showed that correlated hardware failures occur in large-scale Internet systems. They attributed this to the machines' dependence on common resources such as disk servers, naming servers, maintenance activities, and power supply.

Incident	Fault Chain	Coupling	Downtime
Youritdepot.com outage [9]	• Loss of internal power distribution unit causes a failure in air conditioning • Temperature spikes to more than 113ºF. • The heat caused equipment failure and resulted in significant loss of internet traffic	Tightly coupled	Several hours
MSN Messenger outage [10]	• Disk controller of primary database server fails • Backup for this controller also has an error occur which results in a more lengthy path to full service recovery	Uncoupled	6 days (Intermittent outages)

Table 4: Examples of fault-chains

4 Prevalence of Failures

Studies suggest that user-visible failures in Web applications are prevalent. A survey done by TeaLeaf in October 2005 indicates that 89% of all online customers have experienced problems when completing transactions online [11]. A separate survey [2] of the forty top-performing Web sites during the 2002 holiday shopping season found that 72.5% of these sites exhibited application failures within the first fifteen minutes of testing. These failures included blank pages, incorrect data shown on Web pages, incorrect items displayed in response to a user request, and the inability to complete a purchase.

Human/operator error and application software failures account for a significant proportion of these failures [3 and 9]; hardware failures account for 10% or less of all failures. The trend represents a shift from the mid-80's when hardware failures were the dominant cause of system failures [8]. The reduction in the proportion of hardware failures is due to a steady increase in hardware reliability coupled with the skill of IT personnel to identify potential faults before they result in user-visible failures.

Although software is a dominant cause of site outages, this does not necessarily imply that software quality has gotten worse over the years. Gray [8] observed that while software complexity had increased dramatically, software fault rates held constant. The increase in software complexity relative to the other components of the system might be the reason why software is a dominant cause of outages.

The other dominant cause of site outages is operator errors. Operator errors typically arise when operators are making changes to the system, e.g., scaling or replacing hardware, or deploying or upgrading software. A study done by Oppenheimer et al [9] suggests that operator error occurred as often as hardware or software problems but was less frequently masked by the redundancy mechanisms in the system, and therefore more likely to result in a user-visible failure. For example, in the content hosting service they studied, less than 24% of hardware and software component failures resulted in user-visible failures whereas half of the operator failures resulted in user-visible failures. Their studies also suggest that operator errors were mostly configuration rather than procedural errors.

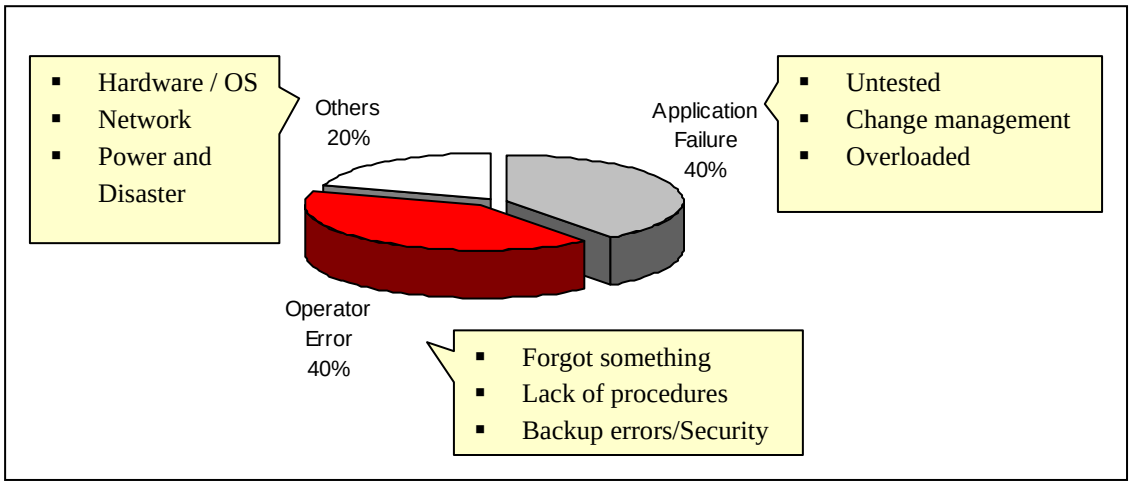


Figure 1: Causes of site failure (Source: Gartner Group- 2001 [3])

5 Planned vs. Unplanned Downtime

A recent study [4] looks at the main causes of downtime in business systems. Although their study does not distinguish between e-business and traditional business systems, it does provide insight on the prevalence of planned and unplanned downtime in businesses as a whole. Their study indicates that planned downtime accounts for at least 80% of all downtime in businesses while the balance of less than 20% is unplanned downtime.

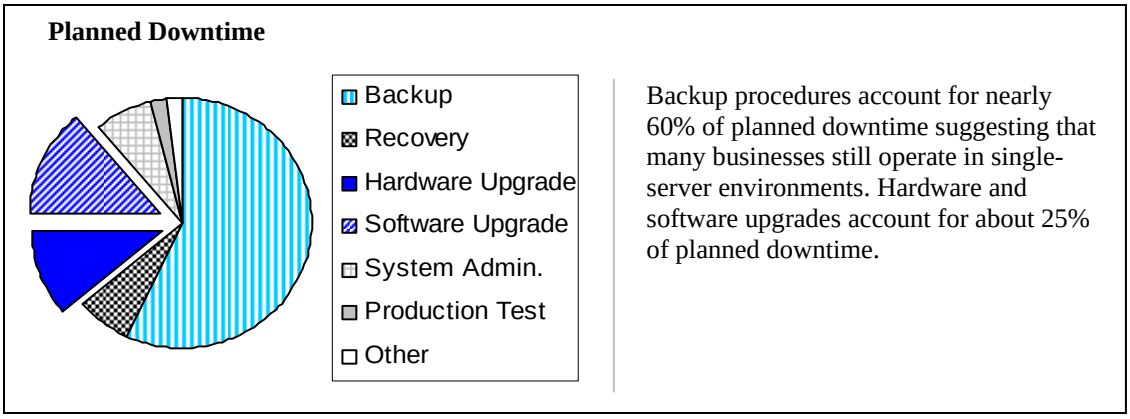


Figure 3: Causes of planned downtime [4]

Planned downtime (Figure 3) consists of: (i) normal IT infrastructure operations like backups; (ii) maintenance activities such as program fixes; (iii) unique periodic events that can be scheduled with substantial lead time like software upgrades and disaster recovery testing. Planned downtime is often a leading contributor to unplanned downtime (operational overruns in Figure 4), for instance, when a backup takes longer than planned.

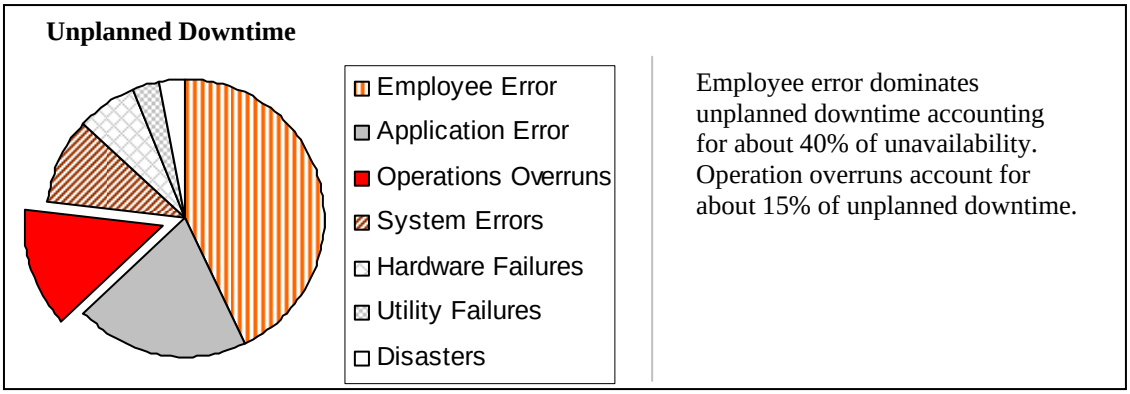


Figure 4: Causes of unplanned downtime [4]

6 Conclusion

Software failures and human error account for about 80% of failures [3]. The incidents of software failures on the Web indicate that a large number of non-malicious failures occur during change management. It is unclear whether these failures are mainly due to system complexity, inadequate testing and/or poor understanding of system dependencies. Other significant causes of software failure are system overload, resource exhaustion and complex fault-recovery routines.

Site outages ranged from a few minutes to several weeks (see appendix). During this period, the site may be completely unavailable or experiencing intermittent outages. Prolonged downtime often occurs when multiple system components are implicated in the failure (i.e. large fault-chains). Some sites resort to periodic restarts to fix problems that they cannot diagnose.

This report contains an appendix that serves as a quick reference for common causes of failures in Internet services. The appendix lists over 40 incidents of real-world site outages, outlining how these failures were detected, the estimated downtime, and the subsequent recovery action.

7 References

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8 APPENDIX: Causes of Failures

8.1 Software Failures: System Software

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
OPERATING SYSTEM *e.g.,* ▪ Memory and resource leaks ▪ Memory access violations ▪ DLL conflicts ▪ Security vulnerabilities ▪ Device driver failures ▪ Failed OS upgrades	Bug in updated module in PlanetLab [12] kernel leads to problems accessing TCP sockets.	Not specified	Users reports	Fixed bug in module.
	Overload on software update server on PlanetLab [12] causes long delays and cron jobs hang for at least 5hrs.	5 hrs	Users report long delays	Nothing -waited for upgrade to complete
	Websites hosted on America Online experience intermittent outages over several weeks due to server upgrade. http://news.com.com/2100-1023-827901.html	Several weeks (intermittent)	Inability to update websites, loading blank pages o	Not specified
CACHE SERVER FAILURE *Cache servers are used as intermediaries for web requests and retain previously requested copies of resources* ▪ Loads stale data ▪ Shopping carts that use IP address to track state of the cart, may fail because interception proxies at ISP level may alter client's IP	Symantec issues patch for DNS cache-poisoning and redirection vulnerability that affects multiple gateway security products in March 2005. Attackers redirected traffic from popular domains such as google.com, ebay.com and weather.com to rogue sites that attempt to load the ABX toolbar spyware onto the victim's machine. http://www.eweek.com/article2/0,1759,1776762,00.asp	Not specified	▪ User reports	Blocked IP addresses of rogue sites Patched DNS servers

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
WEB SERVER AND APPLICATION SERVER FAILURES *A web server is software that serves HTTP pages. An application server sits between the database and the web server and supports business applications.* ▪ Memory leakage ▪ Thread pool exhausted leading to slow or unresponsive server (hangs) ▪ Configuration errors ▪ Web servers buckle under peak load ▪ Resource intensive processes may cause server requests to timeout ▪ Failed upgrades ▪ Fast-growing log files consume disk space and choke the Web server	Stray file conflicts with startup of Omicron web server at asmallorage.com in January 2005. http://forums.asmallorange.com/index.php?showtopic=2409	15 mins	Site unavailable	Removed conflicting file
	Zopewiki.org (open source WAS) experiences memory leak in July 2004. Cause is unknown and the workaround is to reboot the server daily. http://zopewiki.org/ZopeWikiNews	A few minutes daily	Performance slowdown	Daily reboots. Cause unknown.
	Anti-Unix Web site "wehavethewayout.com" experiences 2-day outage. Speculation is that the problem occurred when switching over from FreeBSD and Apache to Windows and IIS or site overload. No official explanation for failure http://news.com.com/2100-1001_3-875884.html	2 days	Site blank	Not specified
	University of Michigan's ICPSR web server goes down in July 2002 when web logs grew too large due to a significant increase in traffic. http://www.icpsr.umich.edu/org/policies/webouts-2002.html	1 hr	Site unavailable	Pruned web logs

8.2 Software Failures: Database[1]

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
DATABASE STATEMENT FAILURE *Failure occurs due to logical failure in handling of a statement* ▪ Reference non-existent table ▪ Insufficient permissions ▪ Flawed query may lead to incorrect computations (application bug) ▪ Inadequate table space allocation for the user/operation	In February 2005, Basecamphq.com database incorrectly flagged table as read-only and resulting in failed updates to table. http://everything.basecamphq.com/archives/000316.php	½ hr	Some visitors to site get "Sorry, something went wrong" error	Fixed permissions on table
	A bug in the new system's query function at BugRegister causes customers doing look-ups on their accounts to see other customer's domain records in February 2001. http://www.internetnews.com/xSP/article.php/598541	Not specified	User reports	Fixed bug and verified correctness of database
DATABASE-PROCESS FAILURE *Failure that prevents a database instance from continuing to run* May result from hardware problem, such as a power outage, or a software problem, such as an operating system crash	Database glitches at Walmart.com cause 9 hrs of downtime in April 2001. http://www.internetnews.com/ec-news/article.php/4_739221	9 hrs	Not specified	Not specified
	Orbitz site experiences downtime in July 2003 due to glitch in database software. http://news.com.com/2100-1017_3-1026450.html	24 hrs	Not specified	Not specified

[1] For a more detailed description, refer to "Continuous Data Availability with Oracle9i Database", An Oracle white paper, May 2001

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
DATABASE-PROCESS FAILURE (CONTD) ▪ Client PC hangs and user state not saved/retrievable ▪ Failure to rollback process on detection of user process failure ▪ Database hangs increasing response times ▪ Number of simultaneous connections allowed is less that the maximum allowed ▪ Configuration errors	US Airways' flight-operation database malfunctioned and grounds American Airlines and US Airways flights in August 2004 http://news.com.com/2100-1016_3-5292245.html	3 hrs	Not specified	System taken offline for 3hrs to remediate
	Overwhelming traffic during launch of Sony's "Star Wars Galaxies" game causes intermittent database errors in June 2003 http://news.com.com/2100-1043_3-1021900.html	1 day (intermittent)	User error messages during registration and user reports of data loss	Not specified
DATABASE-MEDIA FAILURE ▪ Physical problem reading or writing to files ▪ Head media crash ▪ Disk controller failure ▪ Failed backup ▪ Insufficient system memory for database	MSN messenger experiences partial outages for a week due to disk controller failure in July 2001. The backup for this controller also had an error complicating recovery. http://news.com.com/2100-1023_3-269529.html	1 week (partial outages)	Users report missing buddy lists and connection problems.	Reboots and other unspecified methods

8.3 Software Failures: Application Failures

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
RESOURCE EXHAUSTION *e.g.,* ▪ Exhausting file descriptors ▪ Memory leaks ▪ Filling up disk space ▪ Eating up CPU cycles	PlanetLab [12] nodes hang due to application bug which exhausted file descriptors	Not specified	Nodes could not be logged into but pingable	Fixed application bug
COMPUTATIONAL/LOGIC ERRORS	Users at LiveJournal.com who incorrectly answer a captcha (security code) the first time will subsequently receive an error that their answer is incorrect every time following. (March 2005) http://www.livejournal.com/support/	Not specified	User reports	Not specified
	AOL mistakenly deactivates a number of AIM accounts in December 2004 during its regular cycle of opening unused screen names to new users. http://www.eweek.com/article2/0,1759,1739115,00.asp	Several days	Users unable to access accounts	Restored user accounts
	Bug in the ad server at DoubleClick causes 80% drop in ad delivery in August 2000 http://www.clickz.com/news/article.php/442661	1½ hrs	Users saw error messages instead of banner ads	Rerouted traffic away from faulty servers, applied software patch and rebooted servers
	Pricing error on Amazon's UK site lists iPaq H1910 Pocket PC for under $12 instead of regular retail price of $449 http://news.com.com/2100-1017_3-993246.html	2½ hrs	Abnormally high sales volumes	Not specified
	Server glitch at Microsoft Money prevents users from accessing their online personal finance files. Money's servers were unable to recognize usernames and passwords through the Microsoft's Passport authentication and log-in service. http://news.com.com/2100-1012_3-5289896.html	Nearly 4 days (partial outage)	User reports	Not specified

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
SITE OVERLOAD	Comair airlines cancels over 1,000 flights on Christmas Day when its computer systems for reservations crashed after severe weather caused a surge in crew flight re-assignments that knocked out its computer reservations system http://www.internetnews.com/bus-news/article.php/3451981	Several days	Not specified	Not specified
SOFTWARE UPGRADES *e.g.,* ▪ Failure to back up the web-store before upgrade ▪ Files upgraded successfully but did not go "live" after upgrade (failed deployment). ▪ Upgrades performed without checking inter-compatibility between existing or newer software processes ▪ Software upgrades sometimes sets all options to 'default' automatically after the installation is complete	Comcast suffers 24hr email outage due to problems with email distribution service in March 2004 on the same day that the cable giant revamped a Web-based version of the service. http://news.com.com/2100-1032_3-5170281.html	Not specified	User complaints. Performance slowdown	Not specified
	Software glitch blocks Yahoo access for 45 minutes in March 2002. No official explanation for outage but Yahoo was in the process of is in the process of merging its Yahoo Groups and Yahoo Clubs http://news.com.com/2100-1023-864186.html	45 mins	Yahoo Groups unavailable	Not specified
	PayPal battled on-and-off service outages for about five days in October 2004 after upgrading site. They blamed glitches in the software update and waived customer fees for a day http://www.eweek.com/article2/0,1759,1684427,00.asp	5 days (Intermittent outages)	Intermittent outages to the site	Not specified
INTEGRATION ERRORS/THIRD PARTY SOFTWARE FAILURES	eBay's Half.com integration causes feedback ratings to be out of sync for many Half.com sellers in March 2002 http://news.com.com/2100-1017-867028.html http://www.auctionbytes.com/cab/abn/y02/m03/i25/s01	Not specified (Possibly several hours)	User complaints on erroneous fee	Temporary fix: Users asked to log in with suffix "-half" in account
	Integration of separate HP and Compaq implementations of SAP AG's enterprise software costs Americas division of HP's Enterprise Storage Group about $400 million in revenue and $275 million in operating profits. http://www.eweek.com/article2/0,1759,1640523,00.asp	6 weeks (Overran planned 3-week disruption)	Not specified	Not specified
	AOL's attempt to deploy the new client, AOL Anywhere, in April 2002 results in sporadic access to email service http://www.eweek.com/article2/0,1759,125973,00.asp	Over 1 week (Intermittent outages)	Email service unavailable	Rolled back upgrade until issues resolved.

8.4 Human Errors

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
CONFIGURATION ERRORS *e.g.*, ▪ System reset to default by mistake ▪ Software configured incorrectly ▪ Corrupted the configuration file by mistake ▪ Omit necessary services from startup script	Human error during scheduled maintenance causes outage at Orbitz.com in July 2003 http://news.com.com/2110-1017_3-5053617.html	Several hours	Not specified	Not specified
	Incorrect configuration change in January 2001 to the routers on the edge of Microsoft's DNS network disrupts Microsoft.com, MSN.com, MSNBC.com, Hotmail.com and Encarta.com. http://www.internetnews.com/xSP/article.php/570171	Ranged from several hours to 1 day	Sites unavailable	Not specified
	MSN mistakenly lists incoming messages from Earthlink and RoadRunner as spam and blocks them. Speculation this was due to operator error. http://news.com.com/2100-1025_3-990653.html	Not specified	Users complain that email to MSN not being received	Earthlink and RoadRunner put on "safe list"
PROCEDURAL ERRORS *e.g.*, ▪ Failure to back up database ▪ Restoring the wrong backup ▪ Forgetting to restart web server ▪ Deleting files by mistake ▪ Incorrect input, typos etc ▪ Forgetting to prune web logs (disk fills up)	Gforge3 site down due to failure to restart database daemon after applying database patch (December 2003) http://fms.gfdl.noaa.gov/forum/forum.php?forum_id=30	Not specified (possibly several hours)	Site unavailable	Restarted database daemon
	University of Michigan's ICPSR web server goes down in July 2002 due to web logs that were too large (about 2GB) due to a significant increase in traffic. http://www.icpsr.umich.edu/org/policies/webouts-2002.html	1 hr	Site unavailable	Pruned web logs
MISCELLANEOUS ACCIDENTS *e.g.*, ▪ Equipment trauma caused by drop or fall ▪ Accidentally disconnect power supply	Anne Lear [6] reports eBay incident where electrician came in to audit power usage and on his way out accidentally knocked out a plug. The device he unplugged had a backup battery, so nobody knew anything was wrong until 30 minutes later when the battery ran down and the device went out, taking the system down with it.	Not specified	System unavailable	Restored power

8.5 Hardware Failures

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
EQUIPMENT AND DEVICE DRIVERS FAILURES *e.g.*, ▪ Device driver failures ▪ I/O errors, e.g., hard disk failures (see database media failures) ▪ Memory parity errors ▪ Overheating	PlanetLab[12] nodes crash due to Ethernet driver that was incompatible with new OS. Failure occurs under heavy system load. Crashes persist for several weeks.	Several weeks (Intermittent failures)	User notices node crash	Temporary fix: Reboot nodes Permanent fix: Updated kernel
	Hardware failure at the Wall Street Journal website causes 1hr outage in March 2004 http://news.com.com/2110-1025_3-5171623.html	1 hr	Not specified	Not specified
	Customers of Apple Computer's .Mac online services unable to access their information for several hours due to equipment failure in October 2002 http://news.com.com/2100-1040_3-961055.html	Several hours	Not specified	Installed new equipment
	Yahoo Groups down for several hours due to hardware problems in March 2002 http://news.com.com/2100-1023_3-851276.html	Several hours	Yahoo Groups unavailable	Not specified
POWER OUTAGES	Power outage on e-bay's web hosting facility cripples site for 3 hrs in August 2003 http://news.com.com/2100-1017_3-5066669.html	3hrs	Not specified	Power restored
	Power outage knocks LiveJournal blogs offline for about 24 hrs in January 2005 http://www.eweek.com/article2/0,1759,1751832,00.asp http://www.livejournal.com/powerloss/	24hrs	Site unavailable	Restored power. Restored data from backups but some backups were corrupt so service restoration took longer than planned
	Loss of internal power distribution unit at youritdepot.com in August 2004 causes a failure in air conditioning and temperature spikes to more than 113ºF. The high heat caused equipment failure and resulted in significant loss of internet traffic. http://www.youritdepot.com/index/nid/147	Several hours	Not specified	Not specified
HARDWARE UPGRADES	iWon experiences intermittent outages after installing $2 million worth of new hardware to handle increased traffic when switching Excite email users to new system in January 2002 http://news.com.com/2100-1023_3-803872.html	Several days (Intermittent failures)	Email service unavailable	Not specified

8.6 Network Failures

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
EQUIPMENT AND DEVICE DRIVERS FAILURES *e.g.*, ▪ Network congestion ▪ Performance issues ▪ Configuration errors. ▪ Node or link inoperative ▪ Failures in underlying telecommunication switching systems ▪ Router failures ▪ Network adapter fails at the server site ▪ Network hardware failures/ link failures ▪ Copper cables damaged/cut/ corrosion/magnetic interference	PlanetLab[12] experiment overloads university's Internet connection	Not specified	System administrator observes bandwidth spikes	Placed a per-node bandwidth cap
	Network connection problems slowed Bank of America's online banking service experiences several days of sporadic outages and slow service in February 2001 http://news.com.com/2100-1017-252715.html	Several days (Intermittent outages)	Performance slowdown	Not specified
	Network interruption causes of BlackBerry outage for 15 hrs in February 2003 http://www.eweek.com/article2/0,1759,1661386,00.asp	15 hrs	Several customers experienced long delays in receiving e-mail	Backup node takes up service operation while Blackberry and Cingular work to restore service.
	ISP in Virginia (MAI Network services) passes bad routing information to Sprint causing network outage http://news.com.com/2100-1033-279235.html	2hrs	Abnormal traffic flows	Reset routing tables

8.7 Security Violations

FAILURE	EXAMPLES			
	INCIDENT	DOWNTIME	DETECTED	RECOVERY
SECURITY BREACHES *e.g.*, ▪ Password disclosures ▪ Cross-site scripting ▪ Denial of Service (DOS) attacks ▪ Worms and viruses ▪ Browser vulnerabilities ▪ Authentication failures ▪ Theft	DOS attack on Microsoft's corporate website causes 1 hr outage in August 2003 http://computercops.biz/article2609.html	1 hr	Site unavailable	Not specified
	DOS attack on Akamai's DNS servers causes 2hr site outage on Google, Yahoo, Apple and Microsoft in June 2004 http://news.com.com/2100-1038_3-5236403.html	2hr	Sites unavailable	Not specified
	MyDoom worm causes outage for several outage on Google, Altavista and Lycos in July 2004 http://news.com.com/2100-1023_3-5283750.html	Several hours (Partial outage)	Site unavailable/ Performance slowdown	Not specified
	Theft of network cards from a Verizon central office in New York has caused some customers there to lose their Internet access for a day in May 2004 http://www.eweek.com/article2/0,1759,1583346,00.asp	1 day (Partial outage)	Not specified	Restored service using backup network cards