

Chapter 6

An Introduction to Debugging

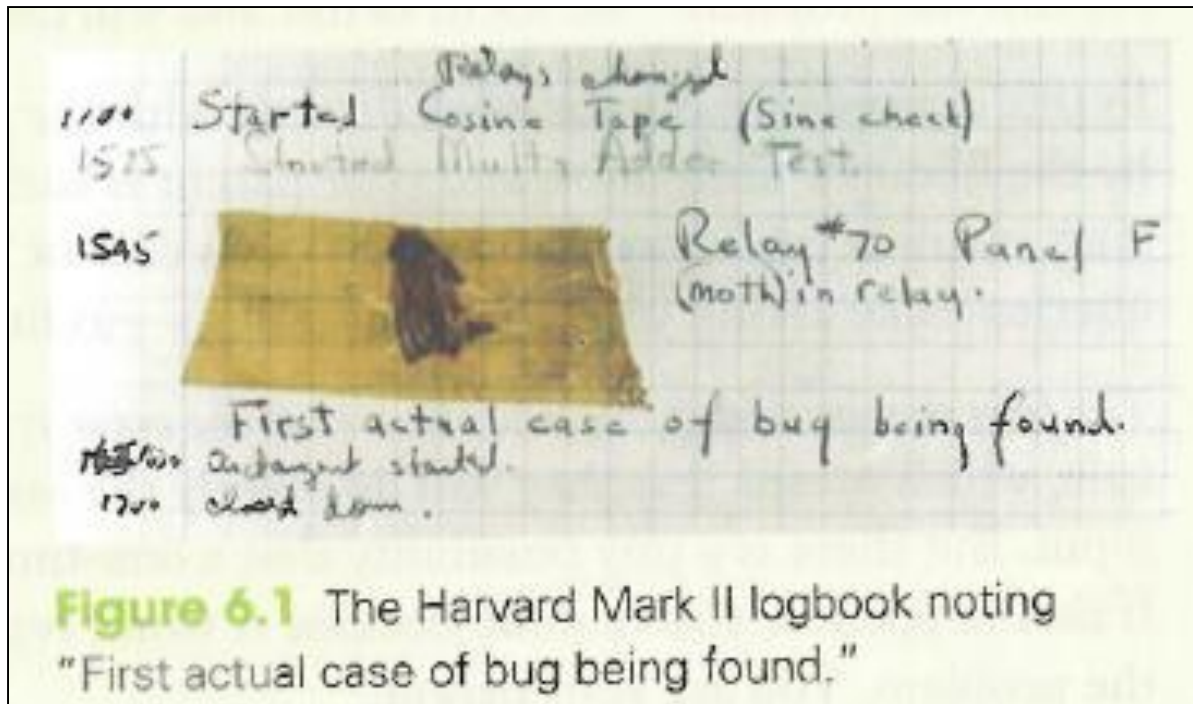
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Learning Objectives

- Explain how ordinary precision differs from computing precision
- Describe the six-step strategy for debugging
 - Explain the purpose of each step
 - Give an example of each step
- Apply the 6-step strategy for debugging the HTML code for a Web page
- Learn how to approach debugging when you don't understand the system
- Appreciate the problems of making perfectly reliable computing systems

The Real Bug: Moth!



- In 1940, a moth was jammed in one of its relays (electro-mechanical switches), bringing the machine down!
- The first bug in the computer history!

Very Boring Feedback Message for an Error in Page 147!

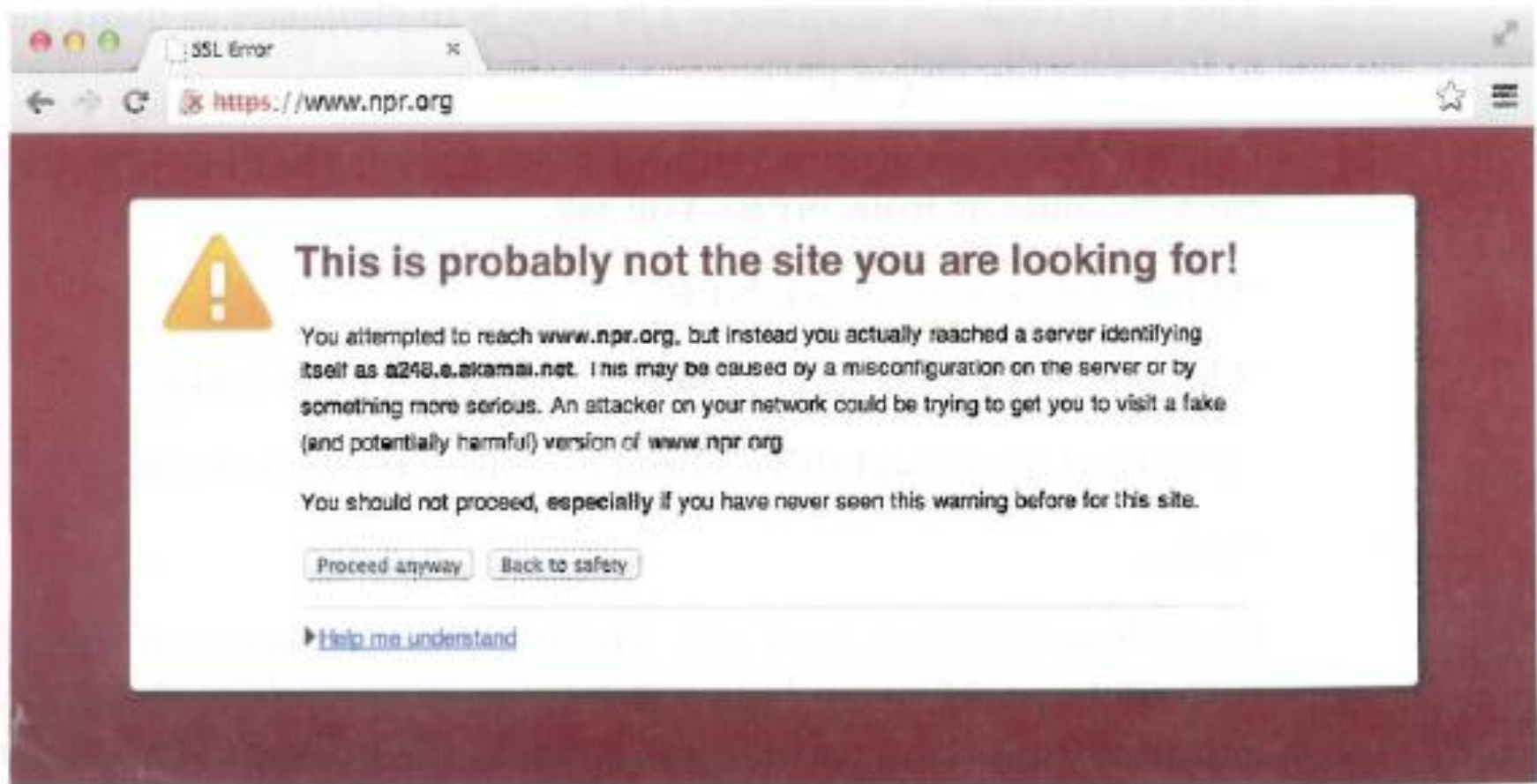


Figure 6.2 Diagnostic message from Chrome, seen by the parent in the story.

Precision: The High Standards of Computing

- Humans make mistakes, usually unknowingly
- But what about mistakes in writing computer programs?

Be Accurate

- Be aware of some possible mistakes
 - Recognizing mistaken substitutions: **I** for **1**, **O** for **0**, **** for **/**, and so forth
 - Knowing that certain fonts can be very confusing: Corbel zero (o) and oh (o)
 - Respecting uppercase and lowercase in pathnames (www.ex.org/AllMine.html is not the same as www.ex.org/allmine.html)
 - Respecting uppercase and lowercase in passwords

Be Observant

- A principle of computing is that you should expect feedback when interacting with software
- We rely on this feedback (busy icons, etc.)
- By paying attention to feedback, we can catch errors as we make them



What's the Problem?

- Debugging is a process by which one figures out why something isn't working properly
- Debugging relies mostly on **logical reasoning** and is learned **through experience**
- Debugging in Everyday Life
 - Debugging is troubleshooting
 - Humans do it all the time (why didn't the car start? why didn't the alarm go off?)
 - **Faults and failures in everyday life** usually involve devices that are working systems with a broken or worn-out part
 - The system is properly designed and constructed, **but some part failed**

Debugging in IT

- Debugging in computation is different from real life fault fixing
- We may have entered wrong data or wrong configuration information into a working system.
 - When it's corrected, the system works.
- Or we might have a logical design error
 - we don't get what we think we should get
- So, we better always begin by assuming the system is correct and working

Whose Problem Is It?

- When debugging a computing system, we are almost always **part of the problem**
- Two of the 3 possible problems with the system involve **us**:
 - **wrong data**
 - **wrong command**
 - **broken system**
- We don't knowingly make errors...therefore we think that we must be right! And the computer is at fault!
- Sometimes it is: both hardware and software errors do happen
- **But! Human errors occur more often..**

Using the Computer to Debug

- Not only is the computer unable to debug itself, we can't debug it directly
- **Workaround:** Bypassing an error and continuing to use the system
 - Bugs in commercial SW are usually not fixed until the next version is released!
- We have to ask the computer
 - What data it has stored (We put some extra “print statements” for error catching)
 - To run the faulty software and show the error list
- More About Debugging
 - Debugging is solving a mystery
 - By asking questions (“Do I need more clues?”; “Are my clues reliable?”) we focus and discover a solution faster

6 Debugging Strategies

- The 1st step in debugging is to check that the error is reproducible
- The 2nd step is to be sure that you know exactly what the problem is
- The 3rd step is to check all of the “obvious” error sources
- The 4th step is to divide the process (isolate the problem!), separating the parts that work from the part that doesn't
- The 5th step: When you reach a dead end, reassess your information, asking where you may be making wrong assumptions or conclusions; then step through the process again
- The 6th step: As you work through the process from start to finish, make predictions about what should happen and verify that your predictions are fulfilled

A Debugging Case Study

- To illustrate the debugging principles in action, imagine a simple page in HTML
- The goal is to get a page that looks like this:

Jackie Joyner-Kersey -- All-Time Best Female Athlete

It sounds bold to claim that Jackie Joyner-Kersey is the absolute best female athlete, but consider this: She competed in the heptathlon, a track and field event that combines scores from seven different sports. She won two Olympic **gold** medals in heptathlon (and a **silver**), and still holds the world record for greatest number of points ever scored: 7,291.

How good was she? First, she competed in heptathlon, meaning she was Olympic caliber in 100m hurdles, 200m, 800m, high jump, long jump, javelin and shot put. Also, she won Olympic **gold** in long jump and two **bronzes**. Add to that two World Championship **gold**s in heptathlon and two **gold**s in long jump, and a long jump **gold** in the Pan American Games. She also played starting forward all four years of college at UCLA in basketball.



Jackie Joyner-Kersey Competing in High Jump

No One Better. But probably the most impressive fact about her abilities is that only two other women have ever been able to score more than 7000 points in heptathlon, Carolina Klüft (7032) of Sweden and Larisa Turchinskaya (7007) of the Soviet Union. For comparison, the table at right lists the seven sports of heptathlon, JJK's 7291-year (1988), her personal best, and the performance needed in each of the seven sports to earn 1000 points. (The scoring in heptathlon is bizarre.)

Event	JJK in 1988	Personal Best	1K Points
100 m hurdles (s)	12.69	12.61	13.85
high jump (m)	1.86	1.93	1.82
shot put (m)	15.80	16.00	17.07
200 m (s)	22.58	22.30	23.80
long jump (m)	7.27	7.49	6.48
javelin throw (m)	45.88	50.08	57.18
800 m (s)	128.51	128.51	127.83



JJK Stats -- Italic Shows Events Where JJK Best 1K

Inspiration Jackie Joyner-Kersey has said in her autobiography *A Kind of Grace* that as a young girl she was inspired to be a versatile athlete by a movie about Babe Didrikson Zaharias, who was a track star, basketball player and pro golfer, and ironically, considered the All-Time Best Female Athlete before JJK.

Look Closely At the Page: Not Working Page..Firefox 25.0

Jackie Joyner-Kersee — All-Time Best Female Athlete

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Jackie Joyner-Kersee Competing in High Jump

JJK Stats — Below Shows Events Where JJK Beat 1K				JJK autobiography
Event	JJK in 1988	Personal Best	1K Points	
100 m hurdles (s)	12.69	12.61	13.85	
high jump (m)	1.96	1.93	1.82	
shot put (m)	15.80	16.00	17.07	
200 m (s)	22.56	22.30	23.80	
long jump (m)	7.27	7.49	6.48	
javelin throw (m)	45.68	50.08	57.18	
800 m (s)	128.51	126.51	127.63	

Figure 6.4 The buggy page displayed with Firefox 25.0; notice the differences with Figure 6.3.

Look Closely At the Page: Not Working Page..Safari 6.0

Jackie Joyner-Kersey – All-Time Best Female Athlete

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JJK Stats -- Italic Shows Events Where JJK Beat 1K			
Event	JJK in 1988	Personal Best	1K Points
100 m hurdles (s)	12.89	12.81	13.85
high jump (m)	1.86	1.93	1.82
shot put (m)	15.80	16.00	17.07
200 m (s)	22.56	22.30	23.80
long jump (m)	7.27	7.49	6.48
javelin throw (m)	45.66	50.08	57.18
800 m (s)	128.51	128.51	122.83

Inspiration Jackie Joyner-Kersey has said in her autobiography *A Kind of Grace* that as a young girl she was inspired to be a versatile athlete by a movie about Babe Didrikson Zaharias, who was a track star, basketball player and pro golfer, and ironically, considered the All-Time Best Female Athlete before JJK.

Look Closely At the Page: Not Working Page..Chrome 30.0

Jackie Joyner-Kersey -- All-Time Best Female Athlete

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How good was she? First, she competed in heptathlon, meaning she was Olympic caliber in 100m hurdles, 200m, 800m, high jump, long jump, javelin and shot put. Also, she won Olympic gold in long jump and two bronzes. Add to that two World Championship golds in heptathlon and two golds in long jump, and a long jump gold in the Pan American Games. She also played starting forward all four years of college at UCLA in basketball.

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Jackie Joyner-Kersey Competing in High Jump

JJK Stats -- Italic Shows Events Where JJK Best 1K			
Event	JJK at 1988	Personal Best	1K Points
100m hurdles (s)	12.69	12.61	13.85
high jump (m)	1.86	1.93	1.92
shot put (m)	15.80	16.00	17.57
200 m (s)	22.56	22.30	23.88
long jump (m)	7.27	7.49	6.40
javelin throw (m)	45.66	50.06	57.18
800 m (s)	128.51	128.51	127.83



Figure 6.6 The buggy page displayed with Chrome 30.0.

Jackie Joyner-Kersey -- All-Time Best Female Athlete

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Jackie Joyner-Kersey Competing in High Jump

JJK Stats -- Italic Shows Events Where JJK Beat 1K

Event	JJK in 1988	Personal Best	1K Points
100 m hurdles (s)	12.69	12.61	13.05
high jump (m)	1.86	1.93	1.02
shot put (m)	15.80	16.00	17.07
200 m (s)	22.56	22.30	21.80
long jump (m)	7.27	7.49	6.15
javelin throw (m)	45.66	50.08	51.10
800 m (s)	128.51	128.51	127.83

JJK

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Look Closely At the Web Page

- The best way to get started, is to study the output closely **to see where the errors are**
- The goal is to notice **features that are right** and **features that are wrong**
 - Note that the 4 browsers display the buggy page differently
 - All browsers should show the page exactly the same
 - It is sometimes possible to find a bug by comparing how different browsers show it

Reproduce the Error

- As we begin debugging the HTML:
 - Recall that the first step is **to reproduce the error**
 - Close the browser and reopen the file
 - There is definitely a problem with our HTML!

Determine the Exact Problem

- The next step is **to determine the problem exactly**
 - Look at the displayed page
 - When there are multiple bugs, pick one to concentrate on

(Tools > Web Developer > Web Console)

- In **Firefox**, go to **the Web Console**: Clear whatever errors have accumulated & Refresh the page



Figure 6.9 Web Console report for the buggy JJK page.

```

<!doctype html>
<html>
<head> <title>Jackie Joyner-Kersey</title>
<meta charset="UTF-8"/>
<style>
body {background-color:ivory; font-family:helvetica;
color:sienna; padding-left:80px;width:825px}
h2 {text-align:center}
img {padding:6; border-width:1px; border-style:solid;
border-color:burlywood}
table {outline:solid burlywood thin;font-size:14px }
th {text-align:center;border-width:1px; border-style:solid;
border-color:burlywood;padding:3px}
td {text-align:right;background-color:white;
border-width:1px; border-style:solid;
border-color:burlywood;padding:2px}
td.jjk {background-color:tan; color:white;}
caption {caption-align:bottom;padding-top:4px}
span.au {color:gold}
span.ag {color:silver}
span.bz {color:orange}
</style>
</head>
<body>
<h2 style="color:darkred"> Jackie Joyner-Kersey -- All-Time Best Female Athlete</h2>
<div style="float:right;padding-left:6px">
<p style="text-align:center"><br/>
<span style="font-size:small"> Jackie Joyner-Kersey Competing in High Jump</span><br/></p>

<table> <caption>JK Stats -- Italic Shows Events Where JK Beat 1K</caption>
<tr><th>Event</th><th>JK in 1988</th><th>Personal Best</th><th>1K Points</th></tr>
<tr style="color:red"><td>100 m hurdles (s)</td><td><i>12.69</i></td><td>12.61</td><td>13.85</td></tr>
<tr style="color:blueviolet"><td>high jump (m)</td><td><i>1.86</i></td><td>1.93</td><td>1.82</td></tr>
<tr style="color:blueviolet"><td>shot put (m)</td><td>15.80</td><td>16.00</td><td>17.07</td></tr>
<tr style="color:red"><td>200 m (s)</td><td><i>22.56</i></td><td>22.30</td><td>23.80</td></tr>
<tr style="color:blueviolet"><td>long jump (m)</td><td><i>7.27</i></td><td>7.49</td><td>6.48</td></tr>
<tr style="color:blueviolet"><td>javelin throw (m)</td><td>45.66</td><td>50.08</td><td>57.18</td></tr>
<tr style="color:red"><td>800 m (s)</td><td>128.51</td><td>128.51</td><td>127.83</td></tr>
</table>
<p> <br/> It sounds bold to claim that Jackie Joyner-Kersey is the absolute best female athlete, but
consider this: She competed in the heptathlon, a track and field event that combines scores from
seven different sports. She won two Olympic <span class="au">gold</span> medals in heptathlon
(and a <span class="ag">silver</span>), and still holds the world record for greatest number of
points ever scored: 7,291.</p>
<p><b style="color:darkred">How good was she?</b> First, she competed in heptathlon, meaning
she was Olympic caliber in 100m hurdles, 200m, 800m, high jump, long jump, javelin and shot
put. Also, she won Olympic <span class="au">gold</span> in long jump and two <span class="bz">bronzes.
</span> Add to that two World Championship <span class="au">golds</span> in heptathlon and two
<span class="au">golds</span> in long jump, and a long jump <span class="au">gold</span> in the
Pan American Games. She also played starting forward all four years of college at UCLA in basketball. </p>
<p><b style="color:darkred">No One Better. </b>
But probably the most impressive fact about her abilities is that only two other women have ever
been able to score more than 7000 points in heptathlon, Carolina Klüft (7032) of Sweden and
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sports of heptathlon, JK's 7291-year (1988), her personal best, and the performance needed in
each of the seven sports to earn 1000 points. (The <a href="http://en.wikipedia.org/wiki/Heptathlon">
scoring in heptathlon </a> is bizarre.)</p>
<p><b style="color:darkred">Inspiration</b> Jackie Joyner-Kersey has said in her autobiography <i>A Kind
of Grace</i> that as a young girl she was inspired to be a versatile athlete by a movie about Babe Didrikson
Zaharias, who was a track star, basketball player and pro golfer, and ironically, considered the All-Time
Best Female Athlete before JK.</p>
</body>
</html>

```

Figure 6.8 The buggy HTML code.

Eliminate the Obvious

```

```

- Look for the “obvious” causes & Eliminate them
- What’s the most obvious problem with [a missing image](#)?
 - The file is not where it should be, so the browser can’t find it
 - Check to see that the image is in the pic folder
 - Problem eliminated
- The next most obvious error is [misspelling the file name](#):
 - Check the HTML
 - The path is messed up: It doesn’t mention the pic folder
- After fixing the tag, the image is there!

```

```

- It was an obvious mistake, so checking the “obvious” problems solve it
- [One error down!](#)

Jackie Joyner-Kersey -- All-Time Best Female Athlete

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JJK Stats -- Italic Shows Events Where JJK Beat 1K			
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high jump (m)	<i>1.85</i>	1.93	1.82
shot put (m)	15.80	16.00	17.07
200 m (s)	<i>22.56</i>	<i>22.30</i>	23.80
long jump (m)	<i>7.27</i>	7.49	6.48
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Figure 6.10 JJK page with the th element removed; most styling is now “working,” though it is not yet all correct.

```

<!doctype html>
<html>
<head> <title>Jackie Joyner-Kersey</title>
<meta charset="UTF-8"/>
<style>
body {background-color:ivory; font-family:helvetica;
color:sienna; padding-left:80px;width:825px}
h2 {text-align:center}
img {padding:6; border-width:1px; border-style:solid;
border-color:burlywood}
table {outline:solid burlywood thin;font-size:14px }
th {text-align:center;border-width:1px; border-style:solid;
border-color:burlywood;padding:3px}
td {text-align:right;background-color:white;
border-width:1px; border-style:solid;
border-color:burlywood;padding:2px}
td.jjk {background-color:tan; color:white;}
caption {caption-align:bottom;padding-top:4px}
span.au {color:gold}
span.ag {color:silver}
span.bz {color:orange}
</style>
</head>

```

Error 2. The first diagnostic says there is some sort of problem with the “padding” property in line 9:

```

img {padding:6; border-width:1px; border-style:solid;
border-color:burlywood}

```

```

img {padding:6px; border-width:1px; border-style:solid;
border-color:burlywood}

```

```

<!doctype html>
<html>
<head> <title>Jackie Joyner-Kersee</title>
<meta charset="UTF-8"/>
<style>
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color:sienna; padding-left:80px;width:825px}
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border-color:burlywood}
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border-color:burlywood;padding:3px}
td {text-align:right;background-color:white;
border-width:1px; border-style:solid;
border-color:burlywood;padding:2px}
td.jjk {background-color:tan; color:white;}
caption {caption-align:bottom;padding-top:4px}
span.au {color:gold}
span.ag {color:silver}
span.bz {color:orange}
</style>
</head>

```

12th
line

th {text-align:center;border-width:1px; border-style:solid;
border-color:burlywood;padding:3px}

Error 3. Pushing on, the next diagnostic says, “Dangling combinator. Ruleset ignored due to bad selector.” This is a typical diagnostic—gibberish that means nothing to us. It does say, “ruleset ignored,” confirming that Firefox isn’t bothering with some of our style commands. If only we knew what a “bad selector” is. We could try doing a Web search to find out, but that is an if-all-else-fails idea. We’ll push on to the next diagnostic.

th {text-align:center;border-width:1px; border-style:solid;
border-color:burlywood;padding:3px}

Jackie Joyner-Kersey – All-Time Best Female Athlete

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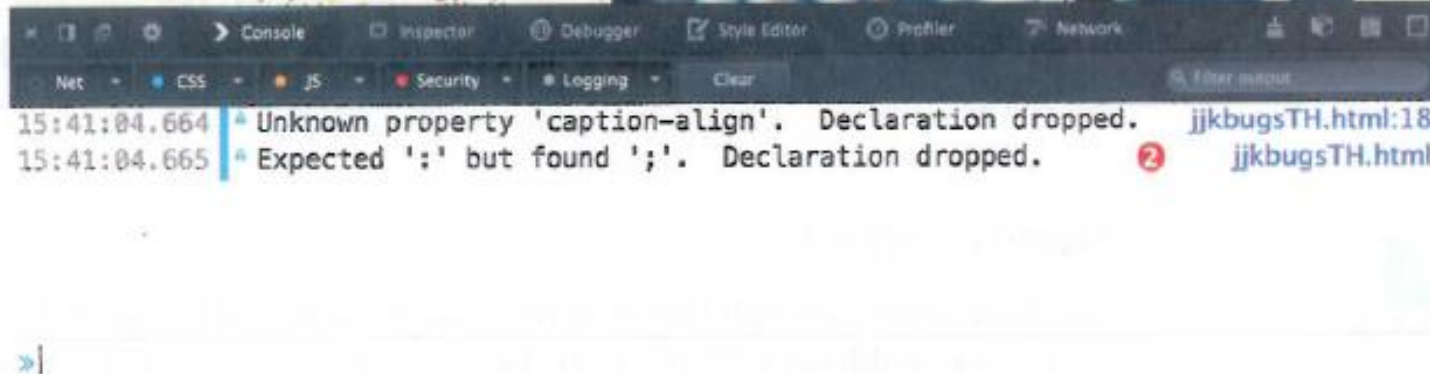


Figure 6.11 Web Console for the JJK page after the third correction.

18th
line

`caption {caption-align:bottom;padding-top:4px}`

`caption {caption-side:bottom;padding-top:4px}`

20th
line

and a long jump `gold ` in the

and a long jump `gold ` in the

Focusing the Bug Search

- We return to the “determine the problem step” and continue with the next bug.
 - Determine the Exact Problem
 - Eliminate the Obvious
 - Divide Up the Process
 - Separate those parts of the system that work from the part that does not
 - This is not always possible to do perfectly

The “Divide Up the Process” Process

- Step through the style section **one element at a time**
 - Delete the entire element
 - Save the file & Refresh the display
 - Check to see that the only thing different is the styling of the removed element
 - Undo the deletion to restore the file to its original form
- If **removing an element** restores other formatting, then we have found the element that is stopping the styling
 - We actually separate the part that is broken from the parts that work (sound familiar?)
- Another approach might be to **reenter the text**
 - Occasionally files get odd
 - **Unprintable characters** can be hard to locate
 - Retyping requires that we consider each part of the styling again, carefully

Debugging the Page: A Postmortem [1/3]

- We debugged the mistakes in the page by [applying debugging guidelines](#):
 - Checked that the book cover file was in the pic folder— [it was](#).
 - Checked the spelling of the file, but found that the path left out the pic part. [Fixed](#).
 - Checked that the end tags were all present— [they were](#).
 - Looked at [the Web Console](#) to find 2 mysterious diagnostics.
 - Checked that the closing braces were all present— [they were](#).
 - Separated working from failing code by a process of delete, check, undo— [found th had stopped styling](#).
 - Checked the th element, and eventually spotted the opening parenthesis. [Fixed](#).
 - Looked at [the Web Console](#) again to find new diagnostics.
 - Looked up “caption-align” to find it is “caption-side.” [Fixed](#).
 - Checked the wrongly colored text, and spotted a typo in the end tag. [Fixed](#).
 - Checked the caption’s small font specification, and spotted a colon typo. [Fixed](#).

Debugging the Page: A Postmortem [2/3]

- An additional common debugging feature: “Correcting” text that isn’t actually wrong because of a wrong conjecture
 - When we’re lucky, we end up changing the program text from correct to correct
 - When we’re unlucky, we change it from correct to incorrect
 - This means “backing out” and restoring the original
- Errors Hiding Other Errors
 - Notice that the errors found were different from the errors we thought we had originally
 - This is very common in debugging:
 - Programmers should never say that they are “down to the very last bug” . . . that bug could be hiding one more!

Debugging the Page: A Postmortem [3/3]

- Asking the System to Help

- The most effective technique was to use [the browser's Web Console feature](#)
- It would have been more effective if the we had better understood the results
- [The Page Source](#) shows color- and font-coded HTML source that tells us how the browser interprets the page
- One of the most powerful debugging techniques is to find ways for the computer to tell us [the meaning of the information it stores](#) or [the effects of the commands it executes](#)
- Having the computer say [how it's interpreting our instructions](#) can separate the case in which we give the right command—but mess up expressing it—and giving the wrong command.

No Printer Output... [1/2]

- You try to print a document and nothing happens...
- The printing problem is solved just like the earlier problems were solved:
 - Reproduce the error
 - Understand the problem
 - Check the obvious causes
- These steps include:
 - Checking the printer's control panel, the paper, the cartridges, the cable connections, the file to be printed, the installation of the printer driver,
 - Whether others can print if this is a shared printer, and
 - Whether you can print a different document

No Printer Output... [2/2]

- Take the next step in the debugging strategy: [Try to isolate the problem](#)
 - Because you have printed before, you know your computer is configured correctly.
 - Try to print a simple document, but it's the same story
 - Unplug the printer from the computer and try again to print
 - Locate [the printer driver's printing monitor](#) to see what files, if any, are listed
- The print queue for your machine:
 - A place where printing tasks wait before being processed
 - The best approach is [to cancel or trash](#) all of the jobs in the queue, and [restart](#) the queue
 - Configure the printer so that it tries to print your files immediately rather than queuing them
 - Is your computer connected/reconnected to your printer?

Ensuring Software Reliability

- Software contains bugs, and crashes are frustratingly frequent
- Most errors are just **an annoyance**
- What about computers that **control life-support systems, medical apparatus, airplanes, nuclear power plants, weapons systems, etc?**
- Errors in these systems are **potentially much more serious**

Coping with Hardware Failures

- Hardware failures can be resolved using techniques such as **redundancy**
 - **Fault-tolerant computing**: Multiple computers performing computations of a safety-critical system
- Another technique is dubbed “**burn in**” (전자제품 테스트)
 - **Infant Mortality Property of HW**: Most errors show up after few hours of operation
 - A computer that has a record of successful operation is likely to continue to operate successfully

* dubbed 별명이 붙은

Coping with Software Failures

- Software is **amazingly complex**
 - Number of possible configurations that a typical program can define grows **exponentially**
 - All these states, known as **reachable configurations**, cannot be examined for correctness
- Programmers begin with **a specification (or a precise description) of the input, how the system should behave, and how the output should be produced**
 - The specification **doesn't say how** the behavior is to be achieved, **just what it should be**
- Programmers produce the program, **test it with sample inputs, and outputs can be checked against the specification**
 - If they do not match, there is a bug and the program must be fixed
 - A program is said to be **correct** if its behavior exactly matches its specification
- It is not possible to know **if the specification is perfect**
- Even if it were, it is not possible **to establish correctness by testing**

The Unavoidable Challenge

- What about the fact that we can't prove that software is correct?
 - Accept that software may contain bugs
 - Refuse buggy software and poorly tested software
- As such, we must be cautious and informed users and take our business to those who produce the best product

Fail-Soft and Fail-Safe Software

- “Safe software” changes the focus from worry about program correctness to concern about the consequences
 - Testing gives confidence that software works “under normal circumstances”
 - It is difficult to test software under unusual circumstances
- There are 2 design strategies: fail-soft and fail-safe (fail-stop)
 - Fail-soft means that the program continues to operate, providing a possibly degraded level of functionality
 - Fail-safe means that the system stops functioning to avoid causing harm
- The strategy is to continue to operate as long as service is safely provided
- Using software to control potentially dangerous systems means taking a risk

Community Debugging

- There **are hundreds of chat sites** where people post their problems, and other people offer help
- If your problem has surfaced before, then a Web search should locate a place where the solution is discussed
- Asking the community is **a good tactic** to keep in mind
- 개발자 site, 동호인 site....

Summary

- What debugging is, why we need to know how to do it, and what the basic debugging strategies are
- To debug a Web page, using the Error Console of the document that shows how the computer interprets the HTML
- How to analyze our debugging performance, noting that debugging involves both correct and incorrect conjectures
 - that it's possible to debug a sophisticated system like a computer printer by using our standard debugging strategy applied with common sense and courage
 - that it is practically impossible to have bug-free software
 - This doesn't mean that we must quit using computers or accept bugs, but we must watch for unusual behavior that might indicate bugs and take precautions to limit the harm that they can cause