Introduction and Security Principles

CS 161 - Lecture 1

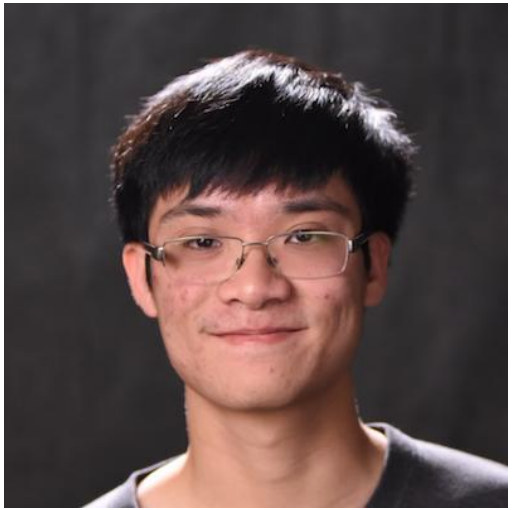
Today

- Introductions
  - Nicholas and Peyrin
  - Course staff
- Course logistics
  - What will you learn in this class?
- What is security? Why is it important?
- Security principles

Introductions

Who Am I? Nicholas

- 3rd-year EECS student
- Took 161 in Spring 2020 and then TA'd for it after that
- Current research interests: Data-oblivious primitives and algorithms in a distributed setting
- I **love** board games! Have definitely missed playing them in person…



Who Am I? Peyrin

- Incoming EECS 5th-year MS student
  - Advisor: Nick Weaver (frequent 161 instructor!)
  - Research focus: CS education (balancing accessibility, cheating detection, student stress, and effectiveness in online exams)
- 7th time teaching 161
  - Feels like I'm stuck in a time loop every time Project 1 releases again…
  - … but it's been fun helping the class grow and adapt to remote semesters!

Actual real picture of me.

And a team of talented TAs and readers!

EvanBot
any/all

TAs

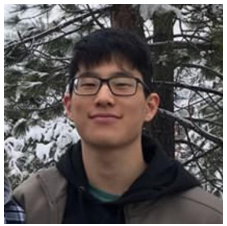
Sid Bansal
he/him

Prachi Deo

Jinan Jiang
he/him

Fuzail Shakir
he/him

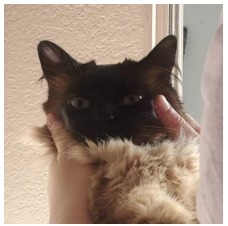
Readers



Jun Hee Han
he/him

Solomon Joseph
he/him

Kenneth Lien
he/him



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Course Logistics

Learning Objectives

- How to think adversarially about computer systems
- How to assess threats for their significance
- How to build computer systems with robust security properties
- How to gauge the protections and limitations provided by today's technology
- How attacks work in practice

Course Outline

- Introduction to Security
  - What are some general philosophies when thinking about security?
- Memory Safety
  - How do attackers exploit insecure software? How do we defend against these attacks?
- Cryptography
  - How do we securely send information over an insecure channel?
- Web Security
  - What are some attacks on the web, and how do we defend against them?

Course Outline

- Network Security
  - What are some attacks on the Internet, and how do we defend against them?
- Miscellaneous Topics
  - Useful, interesting, or fun applications of topics
  - You can use CS 161 knowledge to finish Super Mario Bros. 3 in record time?!

Extra Tools and Skills

- Some extra non-security-related skills you can take away from this class:
- Memory safety
  - x86 assembly: A commonly-used assembly language
  - Using GDB: Debugging C code
- Cryptography
  - Becoming a better consumer: Be able to analyze security products and pick the right security tools for your software
- Web Security
  - Software engineering: Understanding how websites are built and how your web browser interacts with remote web servers (CS 169 preview)
- Network Security
  - Networking: How the Internet works (CS 168 preview)

Prerequisites

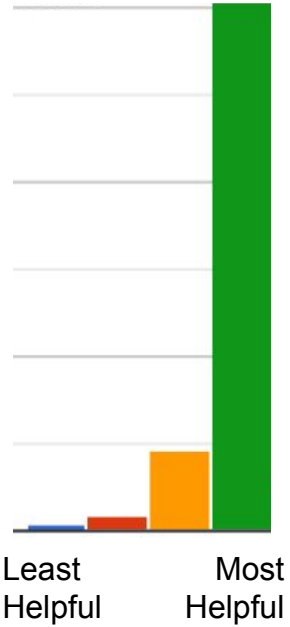
- CS 61B: Ability to work with large and complex codebases, data structures
  - Relevant for Project 2 (500–1000 lines of Go code)
- CS 61C: Familiarity with low-level memory layouts and assembly
  - We'll spend the next lecture reviewing all the 61C material you need to succeed
  - Relevant for the memory safety unit (Project 1, first two weeks of class only)
- CS 70: Familiarity with basic mathematical notation and proof structures
  - Relevant for the cryptography unit
  - We'll review CS 70 material as we encounter it during the cryptography lectures
- An ability to pick up new programming languages quickly
  - Project 2 will be in Go

Course Structure

- Lectures
  - Option 1: Live lectures (Nicholas and Peyrin) (recordings will be posted)
  - Option 2: Recorded lecture videos (Professors Raluca Popa and David Wagner)
- Discussions
  - Attend any discussion section you want
  - Discussion walkthrough videos will be posted
- Office Hours: https://oh.cs161.org/
  - Office hours are posted on the website
- Exams
  - Midterm: Tuesday, July 13, 5:00–7:00 PM PT
  - Final: Thursday, August 12, 5:00–8:00 PM PT
  - Alternate exams will be available if you have a time conflict
- Attendance is always optional! (Except exams)

Resources

- Textbook: https://textbook.cs161.org/
  - Free! There's no textbook you need to pay for
  - Readings are optional, but highly recommended from past students
- Course website: https://cs161.org
  - Course schedule, lecture slides, assigned readings, and other resources are all posted here



Spring 2021 survey: How helpful was the textbook?

Platforms

- Piazza
  - Course-related communication should take place in Piazza or happen in office hours
  - For private matters, you can make a private post
  - Please don’t post publicly about project spoilers!
- Gradescope
  - All assignments are submitted and graded on Gradescope
- Email
  - cs161-staff@berkeley.edu for private matters
  - Piazza response is faster, but staff will monitor the email if you’re more comfortable with that

Grading Structure

- Homework: 15%
- Projects: 30%
  - 3 projects in total, each 10% of your grade
- Optional Labs: 15%
  - If not completed, its score will be replaced by your homework score or project score, whichever is higher
- Midterm: 15%
- Final: 25%

Class Policies: Submission Policy

- Homework
  - Individual
  - Instant feedback: You can keep trying until you get the answer right
  - No credit for late homework, but we drop your lowest homework score
- Projects and labs
  - Individual or groups of 2
  - 1 day late: -10%
  - 2 days late: -20%
  - 3 days late: -40%
  - >3 days late: No credit
  - **You have 3 slip days**, which will be applied optimally to maximize your final grade.

Class Policies: Collaboration

- Asking questions and helping others is encouraged
  - Discussing course topics with other is welcome!
- Limits of collaboration
  - Don’t share solutions with each other (except project partners)
  - You should never see or have possession of anyone else’s solutions—including from past semesters

Class Policies: Academic Honesty

- We’re here to help! There are plenty of staff and resources available for you
  - There’s no need to cheat and find disallowed resources. We have lots of resources for you!
  - You can always talk to a staff member if you’re feeling stressed or tempted to cheat
- Academic dishonesty policies
  - At minimum, the student will receive negative points on the assignment
    - Example: If the midterm is worth 150 points, the student will receive a score of -150 on the midterm.
  - The student will be referred to Nick Weaver and the Center for Student Conduct
    - CSC often doesn’t care that much about first-time cases! They are there to make sure a student doesn’t make the same mistake a second time.
  - If you take the class honestly, you don’t need to worry about these!

Class Policies: Exam Proctoring

- We will be using remote proctoring through Zoom for the midterm and final
  - We've worked hard to make sure the setup is low-stress while preserving exam security
- Logistics are available at https://cs161.org/exam

Class Policies: DSP and Extenuating Circumstances

- Disabled Students' Program (DSP)
  - There's a variety of accommodations UC Berkeley can help us set up for you in this class
  - https://dsp.berkeley.edu/
- Are you facing barriers in school due to a disability?
  - Apply to DSP!
- Our goal is to teach you the material in our course. The more accessible we can make it, the better.
- Shit happens. Do you need an extension or other accommodation?
- Please let us know through our form: https://cs161.org/extensions.html

Stress Management and Mental Health

- We want to reduce your stress where we can
  - Project 2 (mid semester) is going to be the most intensive part of this class, but we've made things lighter towards the end (when every other class has stuff due)

Your health is more important than this course

- If you feel overwhelmed, there are options
  - Academically: Ask on Piazza, talk to staff in office hours, set up a meeting with staff to make a plan for your success this semester
  - Non-academic:
    - Counselling and Psychological Services (CAPS) has multiple free, confidential services
      - Casual consultations: https://uhs.berkeley.edu/counseling/lets-talk
      - Crisis management: https://uhs.berkeley.edu/counseling/urgent
    - Check out UHS's resources: https://uhs.berkeley.edu/health-topics/mental-health

Ethics

- In this class, you will learn a lot about attacks out of necessity
  - To be able to defend against the attacker, you must learn the techniques that attackers use
- It is usually okay to break into your own systems
  - This is a great way to evaluate your own systems
- It is usually okay to break into someone else's systems with their explicit permission
- It is **grossly unethical** and **exceedingly criminal** to break into someone else's systems without their permission

Case Studies and Blue Slides

- Security is often best taught through real-world case studies and stories
  - Lectures will sometimes use real-world examples to demonstrate concepts
  - Slides with a blue background are case study slides
- Content on blue slides are not tested on exams
  - You **do not** need to remember the exact details of the story
- Each blue slide will end in a **takeaway** that describes the moral of the story
  - You **do** need to understand the takeaway from the story

What is security?

Enforcing a desired property ***in the presence of an attacker***

data confidentiality

user privacy

data and computation integrity

authentication

availability

…

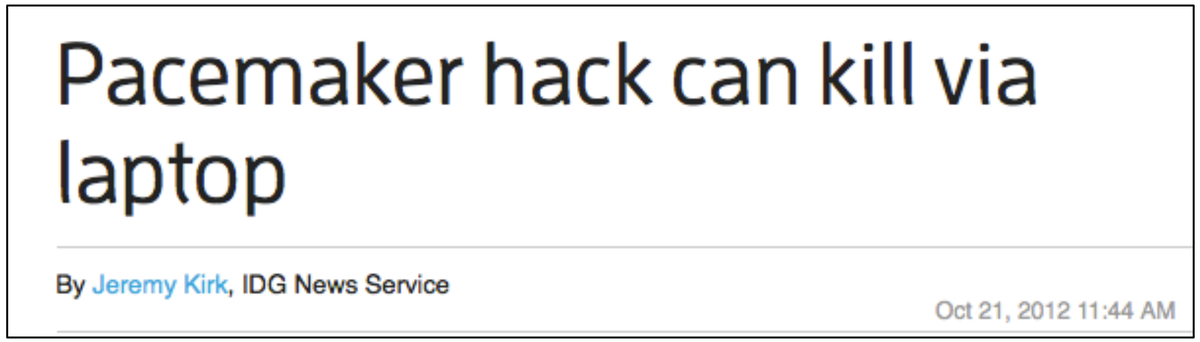
Today's outline

- Why is security important?
- Course logistics
- Intro to security principles

Why is security important?

- It is important for our
  - physical safety
  - confidentiality/privacy
  - functionality
  - protecting our assets
  - successful business
  - a country's economy and safety
  - and so on…

Physical safety threats



Pacemaker hack can kill via laptop

By Jeremy Kirk, IDG News Service

Oct 21, 2012 11:44 AM

Business

FBI probe of alleged plane hack sparks worries over flight safety

Privacy/confidentiality

91% OF HEALTHCARE ORGANIZATIONS HAVE REPORTED A DATA BREACH IN THE LAST FIVE YEARS.

By elxradmin Posted May 29, 2015 In health IT, security 0

EVERYDAY MONEY IDENTITY THEFT

Data Breach Tracker: All the Major Companies That Have Been Hacked

Breaches in 2015 [ITRC]:

- Number of breaches = 5,497
- Number of Records = 818,004,561

Can affect a country's economy... Multiple times!

KIM ZETTER SECURITY 03.03.16 7:00 AM

INSIDE THE CUN
UNPRECEDENTE
UKRAINE'S POW

A Cyber-Weapon Warhead Test

By **Nicholas Weaver** Wednesday, June 14, 2017, 11:38 AM

The *Daily Beast* has a story on "CrashOverride", a computer program best described as transient anti-infrastructure warhead designed to disrupt the power grid. It was tested live against a Ukrainian substation in December 2016 creating a small blackout. Kim Zetter has another good report at *Motherboard*, and Dragos has the technical details.

Dragos attributes the attack as conducted by "ELECTRUM", a group it assesses as being associated with Sandworm—an evaluation that is only slightly better than rolling attribution dice. It is probably more accurate to phrase the attribution as "probably Russia, and probably affiliated with the previous Ukrainian power grid attack in 2015." (The December 2016 attack was the second assault on the Ukranian

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And It Is National Security!

THE WALL STREET JOURNAL.

SIGN IN SUBSCR

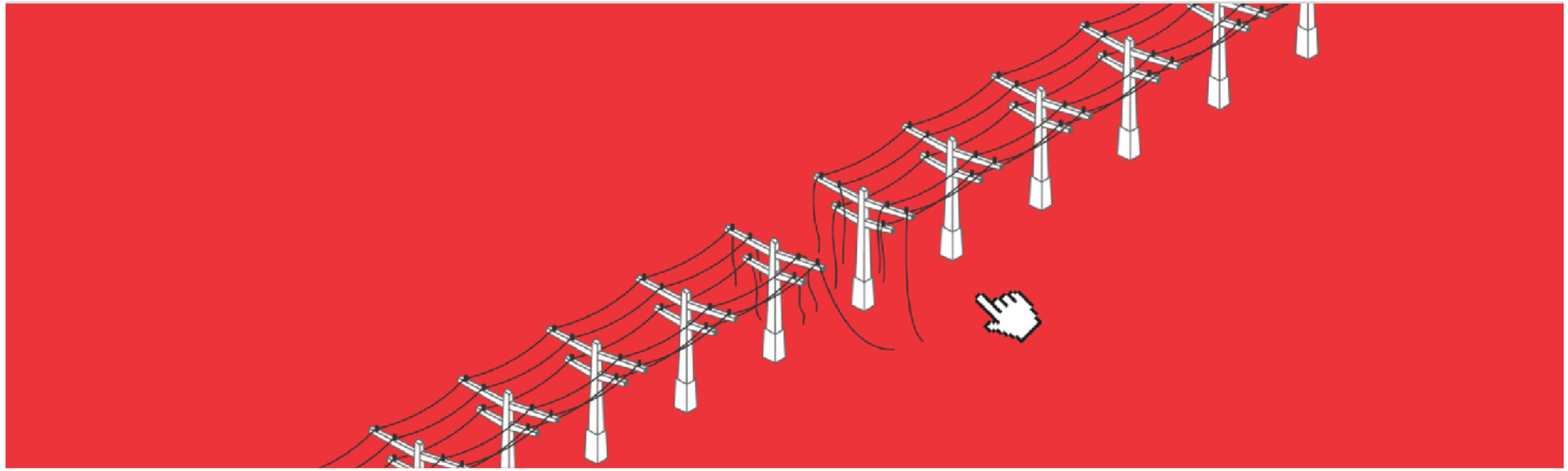


ILLUSTRATION BY JESSICA KURONEN/WSJ

America's Electric Grid Has a Vulnerable Back Door—and Russia Walked Through It

A Wall Street Journal reconstruction of the worst known hack into the nation's power system reveals attacks on hundreds of small contractors

And NotPetya...

- Attackers compromised the update channel for MeDoc
  - Think "TurboTax For Business in Ukraine":
    One of only two accounting packages which Ukrainian businesses can use to pay taxes
- They then monitored for weeks with their backdoor
  - This gave them a foothold in almost all who have business
- Then they released a malicious "worm
  - It spread from computer to computer, and then with a fake "ransomware" payload
    - This cost Mersk shipping alone ***$100M-300M*** in lost r
      White House estimates $10B in damage

SECURITY 08.22.18 05:00 AM

THE UNTOLD STORY OF NOTPETYA, THE MOST DEVASTATING CYBERATTACK IN HISTORY

Crippled ports. Paralyzed corporations. Frozen government agencies. How a single piece of code crashed the world.

BY ANDY GREENBERG

IT WAS A perfect sunny summer afternoon in Copenhagen when the world's largest shipping conglomerate began to lose its mind.

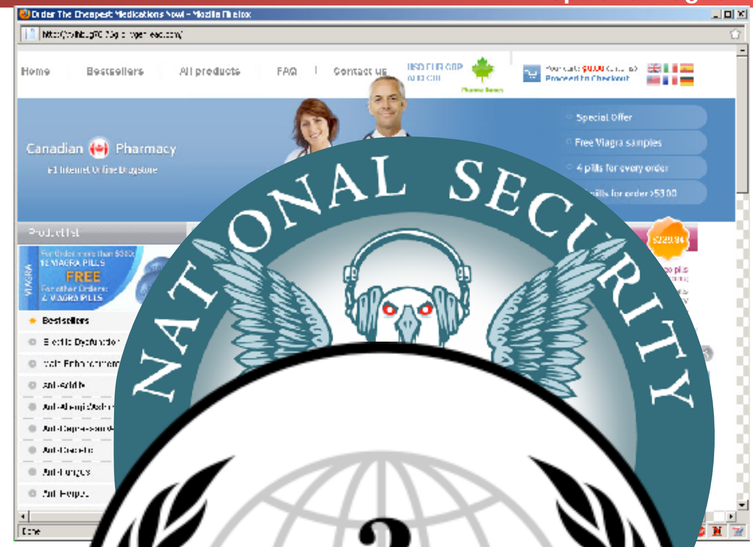
The headquarters of A.P. Møller-Maersk sits beside the breezy

Security Principles

- People and Money
- Threat Model
- Prevention, Detection & Response, Mitigation and Recovery
- False Positives, False Negatives, and Compositions

It All Comes Down To People... The Attacker(s)

- People attack systems for some reason
  - They may do it for money
  - They may do it for politics
  - They may do it for the lulz
  - They may just want to watch the world burn
- Often the most effective security is to attack the attacker's motivation

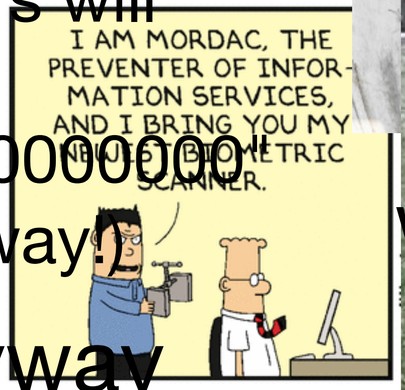


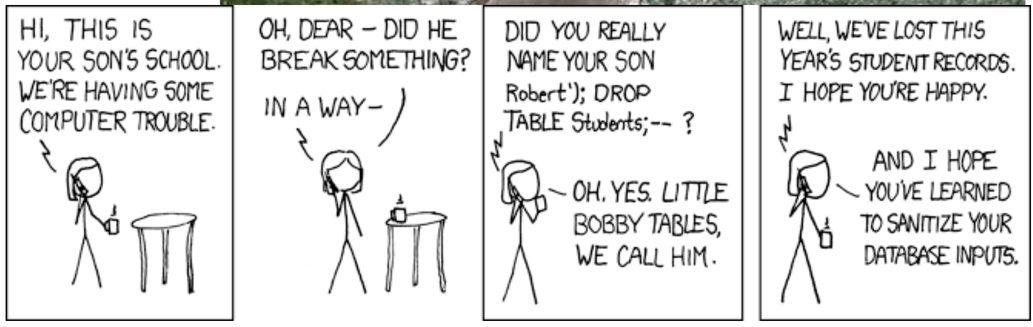
Personal Security: Threat Model...

- Who and why might someone attack ***you***?
- Criminals for money
- Teenagers for laughs or to win in an online game
- Governments
  - Probably not: We aren't important enough
  - And even if important enough we're only worth the B game:
    aka the same things used against us by criminals
- Intimate partners

It All Comes Down to People... The Users

- If a security system is unusable it will be unused
  - Or at least so greatly resented that users will actively attempt to subvert it:
    "Let's set the nuclear launch code to 00000000!"
    (oh, and write down the password anyway!)
- Users will subvert systems anyway
- Programmers will make mistakes
- And Social Engineering...





Don't Blame The Users...

- Often we blame the user when an attacker takes advantage of them...
  - Yet we've consistently constructed systems that encourage users to do the wrong thing!
- Phishing is a classic example:
  - Which is a phishing email and which is an actual email from Chase?

☆ **learningcenter@berkeley.edu** Decemb

UC Cyber Security Awareness Training assigned to Nicholas C Weaver

To: nweaver@cs.berkeley.edu

As part of system-wide efforts to address the increasing threats
our information systems and data, all employees on payroll with a
required to complete the Cyber Security Awareness Training. This
employees.
The training must be completed by January 31st, 2016 and within 6
subsequent new hires.

This mandated training is now assigned to Nicholas C Weaver.

Activity Name: UC Cyber Security Awareness Training
Due Date: 1/29/2016

To access the e-course, click on the UC learning deep link below
the training:

https://uc.sumtotalsystems.com/Shibboleth.sso/WAYF?
target=https://uc.sumtotalsystems.com/secure/auth.aspx?
ru=https://uc.sumtotalsystems.com/sumtotal/app/management/Registr
tion.aspx?ActivityId=230054&entityID=urn:mace:incommon:berkeley.e

For technical questions or concerns contact Campus Shared Service

Email: itcsshelp@berkeley.edu
Telephone: (510) 664-9000, option 1

☆ **Costas Spanos** Inbox - Fastmail 6:21 PM CS

Are you on campus

To: daw@cs.berkeley.edu

Available?
--
Are you available?

No calls only text 7034199290

BEST REGARD

COSTAS SPANOS
Director, CITRIS and the Banatao Institute

Website
University of California, Berkeley 510 Cory Hall Berkeley, CA 94720
Costas Spanos is the Director of CITRIS and the Banatao Institute. He is also the Andrew S. Grove Distinguished Professor of Electrical Engineering and Computer Sciences at UC Berkeley, and the Chief Technical Officer of the Berkeley Education Alliance for Research in Singapore (BEARS). He has served as the EECS Department Chair and the Associate Dean for Research in the College of Engineering at Berkeley. His present research is focusing on energy and sustainability.

David Wagner 6:35 PM DW

Re: Are you on campus

To: Costas Spanos

I am, I am down at Hearst Annex preparing for a lecture this evening. You can call me on my cell if you want, or I can check in after lecture.

See More from Costas Spanos

(703) 419-9290

Hi David

Costas

(703) 419-9290 • 6:50 PM

Hi! D

6:51 PM

What's up, I'm in a meeting right now and I need you to get something done for me.

Costas

(703) 419-9290 • 6:52 PM

Ok, what can I do? D

6:52 PM

Okay, I need you to help me purchase an amazon gift card now, I'll reimburse you back when the meeting is over.

Costas

(703) 419-9290 • 6:55 PM

Today's my friend son birthday

(703) 419-9290 • 6:56 PM

What would you like me to do? D

6:57 PM

I need you to help me purchase an amazon gift card from the nearest store around.

(703) 419-9290 • 6:58 PM

Security often comes down to money...

- You don't put a $10 lock on a $1 item...
  - Unless the attacker can leverage that $1 item to attack something more important
- You don't risk exposing a $1M zero-day on a nobody
  - So I'm quite content to use my iPhone in a hostile network:
    free market cost of a zero-day (unknown/unpatchable) exploit chain for iOS is somewhere between $500k to $1.5M
- Cost/benefit analyses appear all throughout security

Prevention

- The goal of prevention is to stop the "bad thing" from happening at all
- On one hand, if prevention works its great
  - E.g. if you write in a memory-safe language (like Python) you are immune from buffer overflow exploits
- On the other hand, if prevention fails, it can fail hard
  - Example: $68M stolen from a Bitcoin exchange, car
  - Or Ethereum's July 2018: four separate multi-millior theft incidents
  - Or Coinbase accounts: Averaging a theft a day!

Hacked Bitcoin Exchange Says Users May Share $68 Million Loss

by Lulu Yilun Chen t luluyilun Yuji Nakamura t ynakamura56

Detection & Response

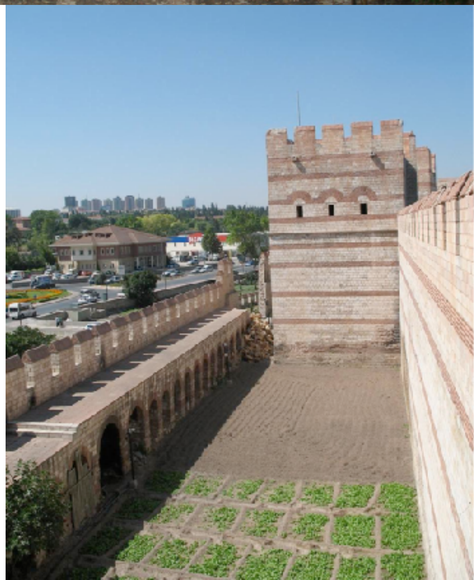
- Detection: See that something is going wrong
- Response: Do something about it
  - Example: Reverse the harmful actions (restore from backup), prevent future harm (block attacker)
  - Need both — no point in detection without a way to respond and remediate

False Positive and False Negatives

- False positive:
  - You alert when there is nothing there
- False negative:
  - You fail to alert when something is there
- Cost of detection:
  - Responding to false positives is not free, and if there are too many false positives, detector gets removed or ignored
  - False negatives mean a failure

Defense in Depth

- The notion of layering multiple types of protection together
  - EG, the Theodesian Walls of Constantinople:
    Moat -> wall -> depression -> even bigger wall
- Idea: attacker needs to breach all the defenses to gain access
- But defense in depth isn't free:
  - You are throwing more resources at the problem



Composing Detectors for Defense In Depth

- The best case: the two detectors are ***independent***
  - With FP1 and FP2 false positive rates and FN1 and FN2 false negative rates
    - Rate is 0-1:
      0 is it never has a false positive/negative,
      1 is it is always a false positive/negative...
- Parallel composition: ***either*** detector may alert to trigger a response
  - ***Reduces*** false negatives: new rate is FN1*FN2
  - ***Increases*** false positive rate: new rate is FP1 + (1-FP1)*FP2
- Serial composition: ***both*** detectors must alert
  - ***Reduces*** false positives: new rate is FP1*FP2
  - ***Increases*** false negatives: new rate is FN1 + (1-FN1) * FN2

Password authentication

- People have a hard time remembering multiple strong passwords, so they reuse them on multiple sites
  - Consequence: security breach of one site causes account compromise on other sites
- Solution: password manager
  - Remember one strong password, which unlocks access to site passwords
- Solution: two-factor authentication
  - Need both correct password and separate device to access account
- Free advice: to protect yourself, use a password manager and two-factor authentication

The Properties We Want in a Safe

- We want the contents to be inaccessible to an attacker
  - But what ***sort*** of attacker?
  - But ***how much time*** does the attacker have?
- We want to ***measure*** how much time & capabilities needed for an attacker
  - For a safe, ratings communicate how much based on experts performing the attack
    - Such security ratings are much harder in the computer security side

Security Rating: A Real Safe

- TL-15:
  - An expert with common tools will take >= 15 minutes to break in

Security Rating: A Stronger Safe

- TL-30:
  - The same expert and tools now takes 30 minutes

Security Rating: A Real Safe

- TL-15:
  - An expert with common tools will take >= 15 minutes to break in

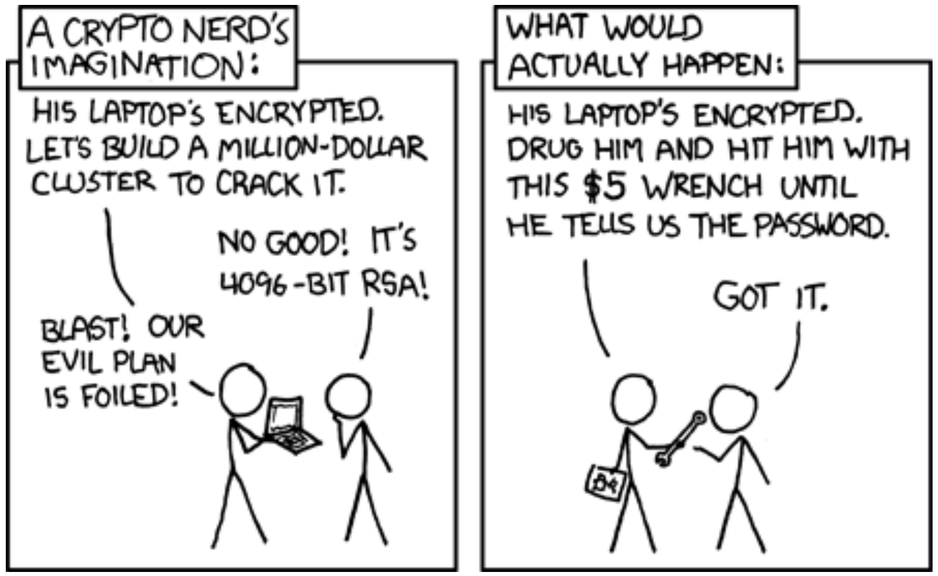
- Quiz: Suppose we sign up for a security alarm service. What guarantees do we need from it, for TL-15 to be adequate?

Security Rating: Now We Are Talking

- TRTL-30
  - 30 minute to break with tools and/or a cutting torch

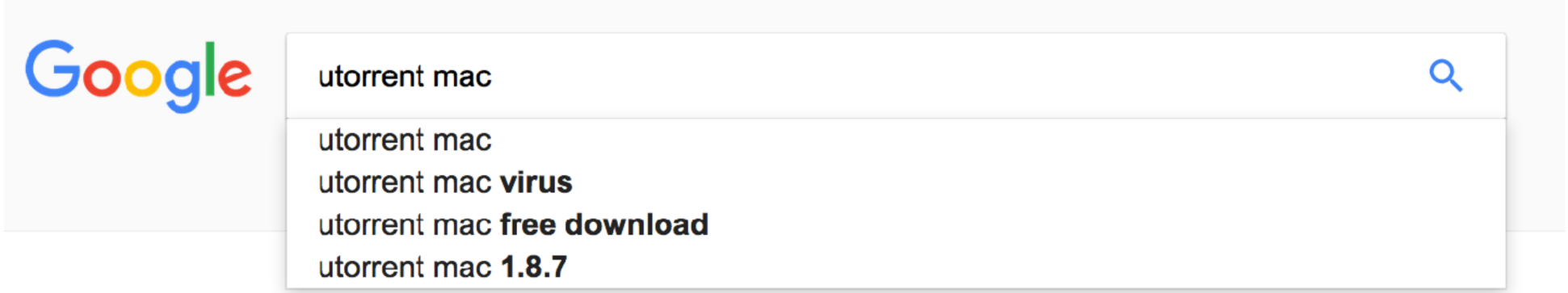
Security Rating: Maximum Overkill...

- TXTL-60:
  - 60 minutes with tools, torches, and up to 4 oz of ***explosives!***
  - Far easier to use "Rubber Hose Cryptanalysis" on someone who knows the combination



Lesson:
Security is economics

- More security often costs more
  - Need to balance expected loss from undefended system, vs cost of defense
- More purchasers often makes security cheaper...



Mac and OSX Downloads - µTorrent® (uTorrent) - a (very) tiny ...

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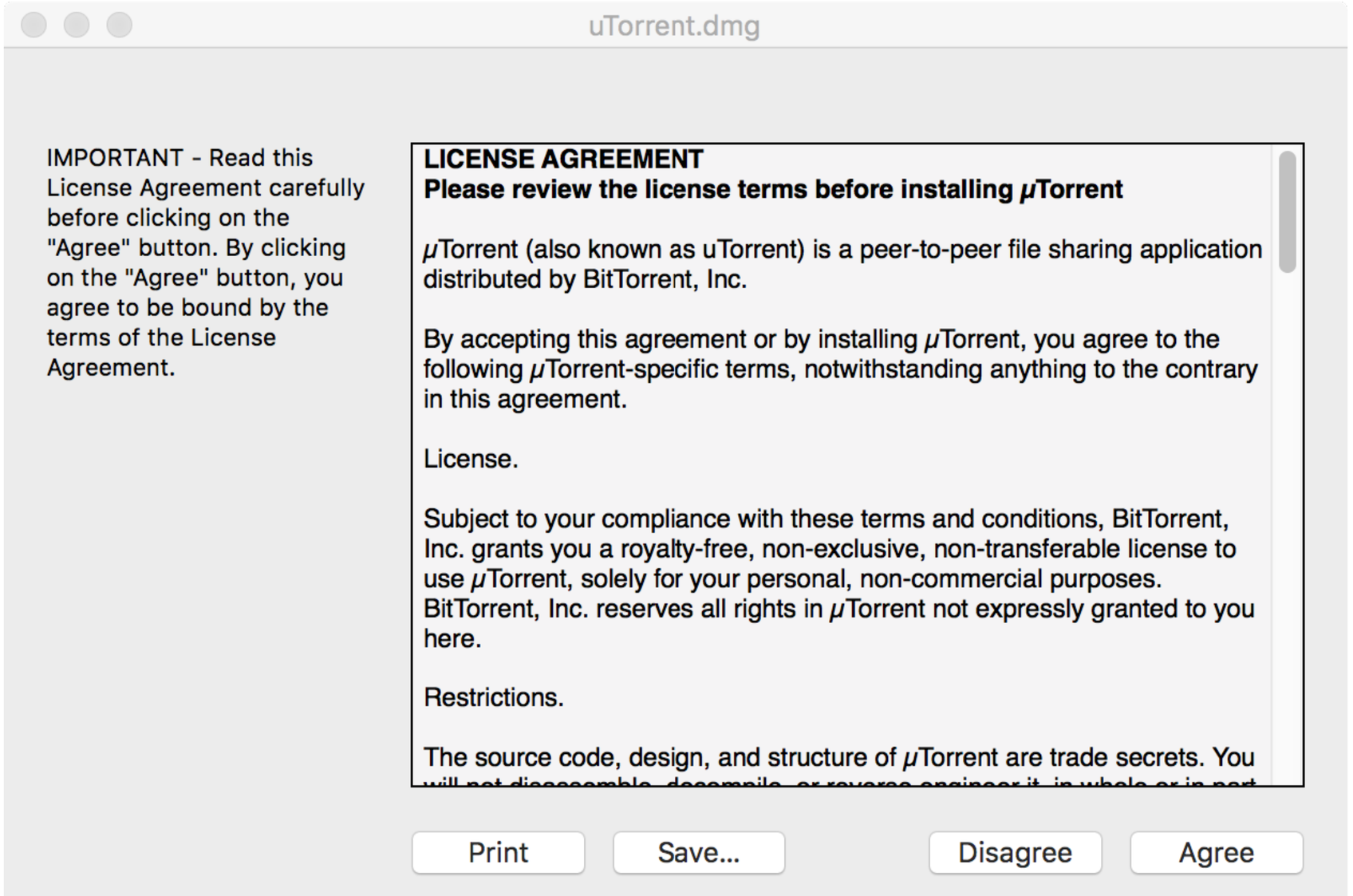
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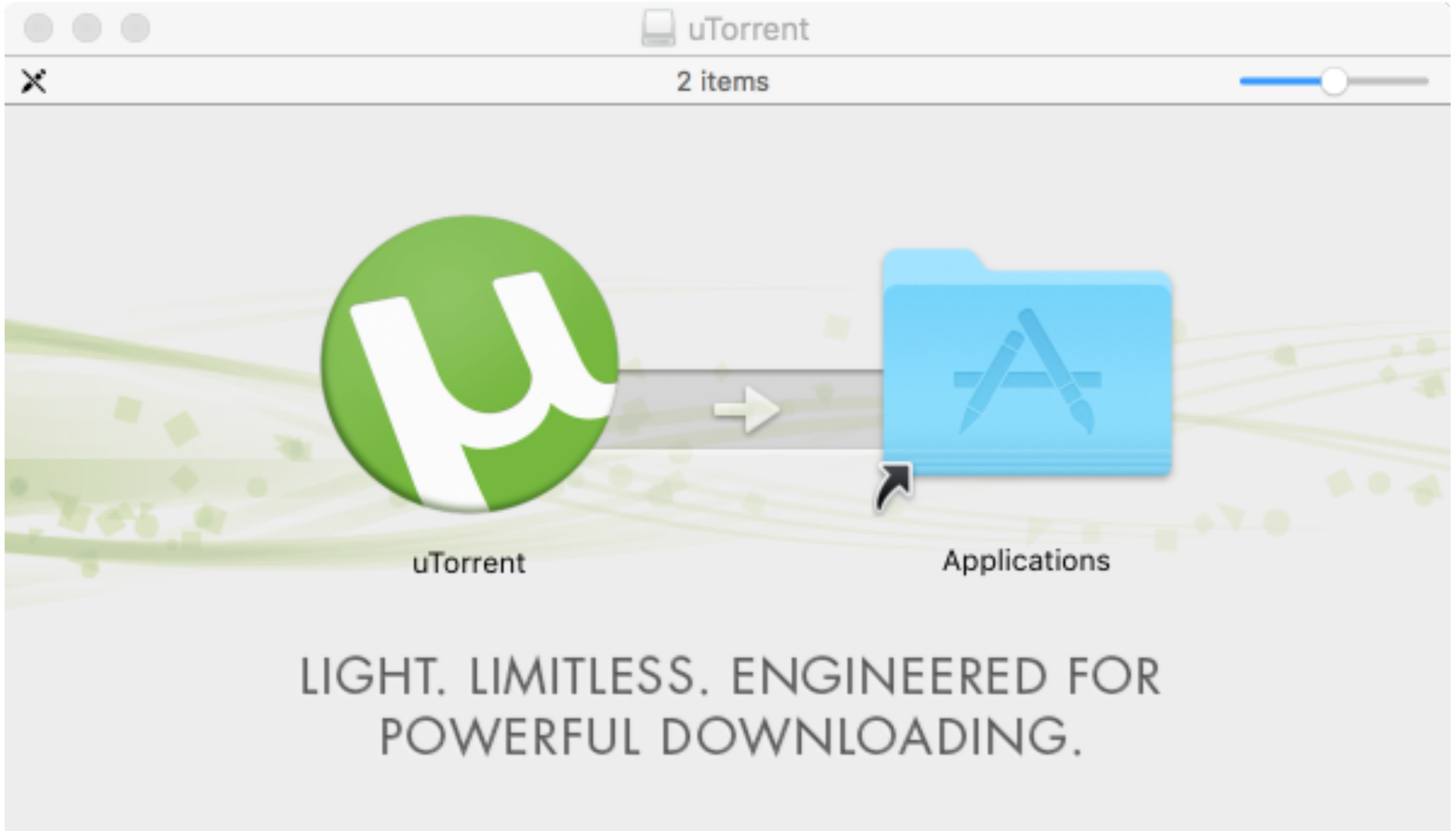
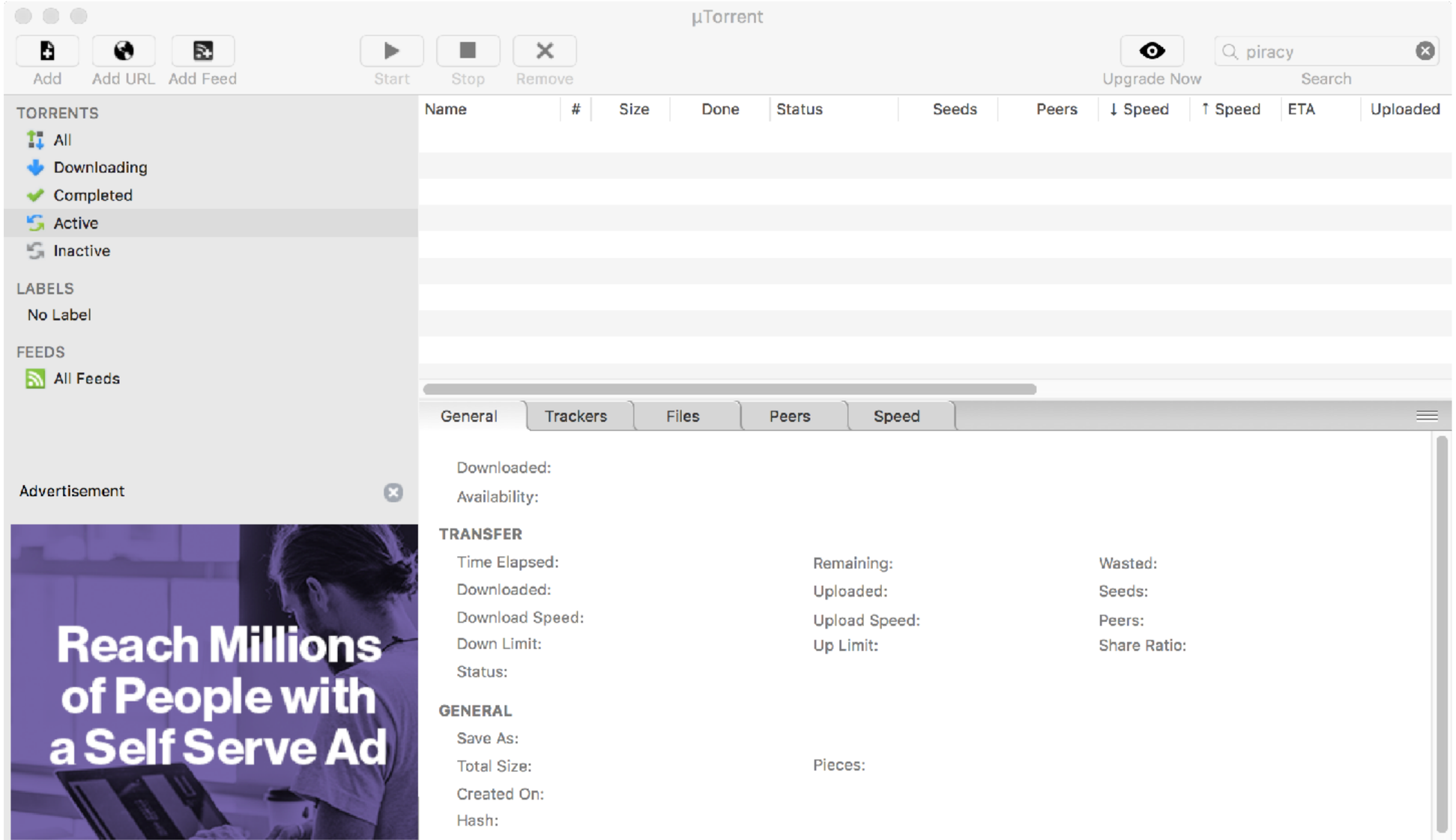
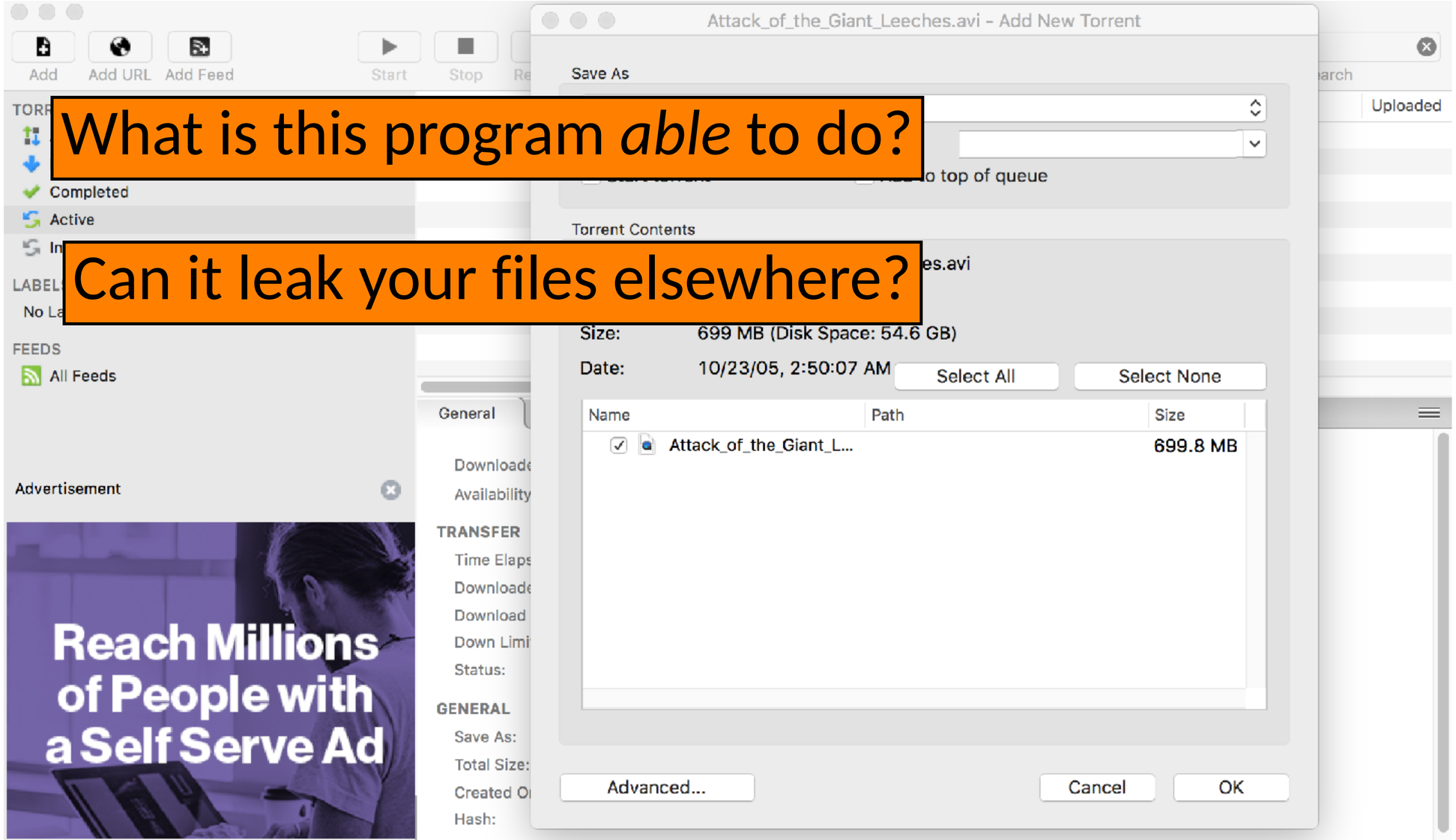
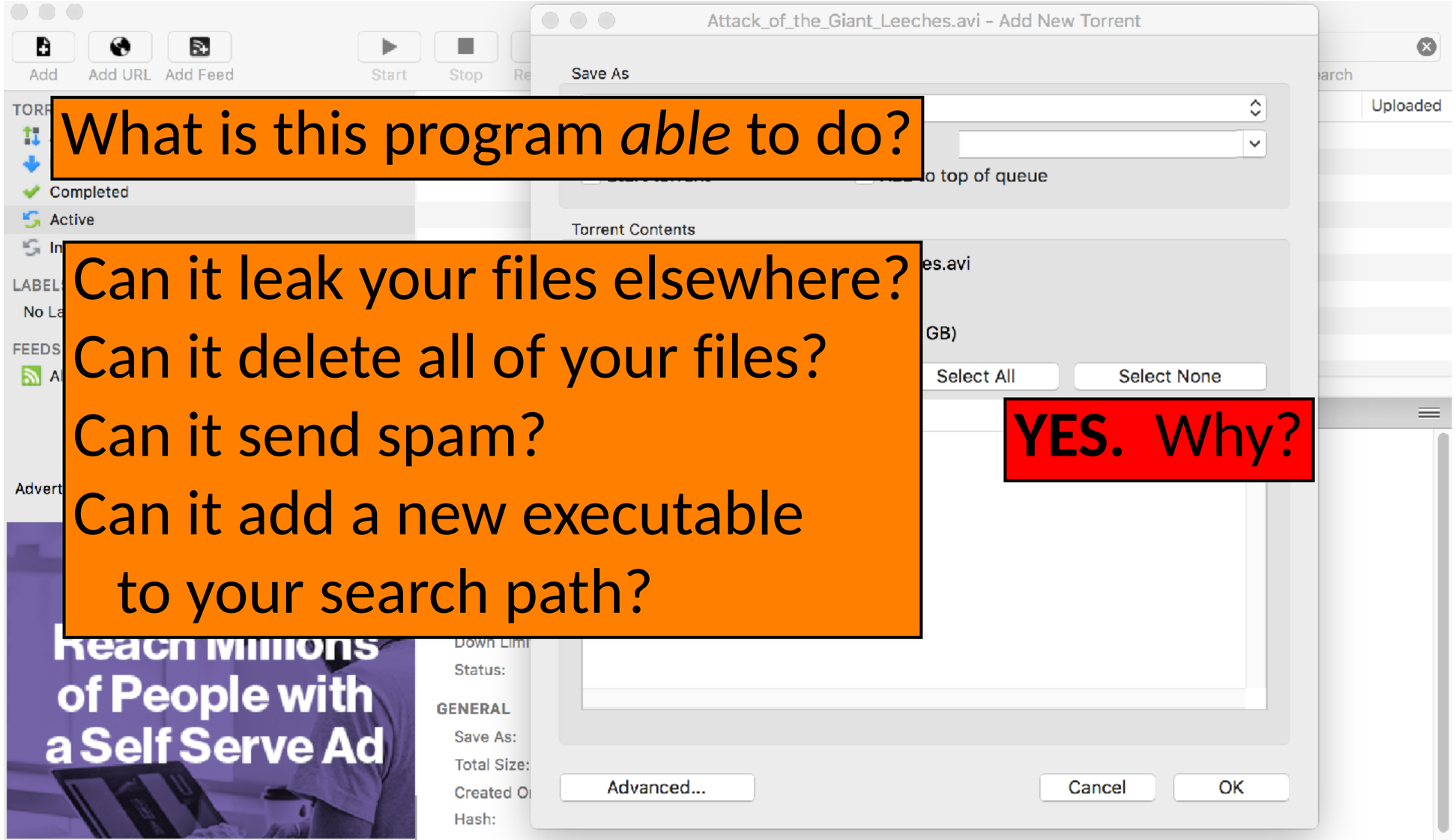
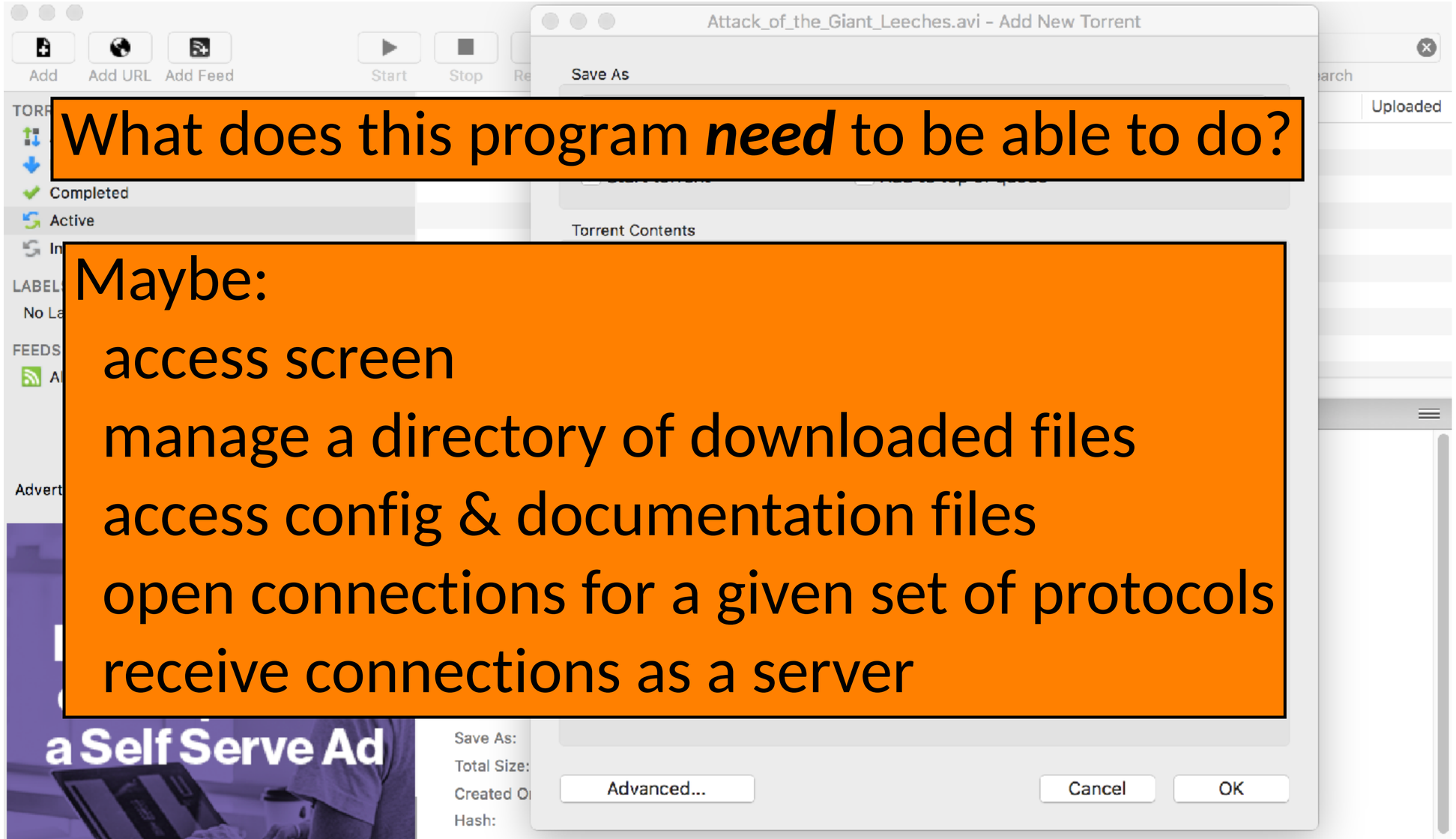
Restrictions.
The source code, design, and structure of µTorrent are trade secrets. You
Print
Save...
Disagree
Agree


uTorrent
2 items
uTorrent
Applications
LIGHT. LIMITLESS. ENGINEERED FOR
POWERFUL DOWNLOADING.


µTorrent
Add
Add URL
Add Feed
Start
Stop
Remove
Upgrade Now
piracy
Search
TORRENTS
All
Downloading
Completed
Active
Inactive
LABELS
No Label
FEEDS
All Feeds
Name
#
Size
Done
Status
Seeds
Peers
↓ Speed
↑ Speed
ETA
Uploaded
General
Trackers
Files
Peers
Speed
Downloaded:
Availability:
TRANSFER
Time Elapsed:
Downloaded:
Download Speed:
Down Limit:
Status:
Remaining:
Uploaded:
Upload Speed:
Up Limit:
Wasted:
Seeds:
Peers:
Share Ratio:
GENERAL
Save As:
Total Size:
Created On:
Hash:
Pieces:
Advertisement
Reach Millions of People with a Self Serve Ad


What is this program *able* to do?
Can it leak your files elsewhere?
Add
Add URL
Add Feed
Start
Stop
Completed
Active
FEEDS
All Feeds
Advertisement
Reach Millions of People with a Self Serve Ad
General
TRANSFER
GENERAL
Save As:
Total Size:
Hash:
Uploaded
Attack_of_the_Giant_Leeches.avi - Add New Torrent
Save As
Torrent Contents
Size: 699 MB (Disk Space: 54.6 GB)
Date: 10/23/05, 2:50:07 AM
Select All
Select None
Name
Path
Size
Attack_of_the_Giant_L...
699.8 MB
Advanced...
Cancel
OK


What is this program *able* to do?
Can it leak your files elsewhere?
Can it delete all of your files?
Can it send spam?
Can it add a new executable
to your search path?
YES. Why?
Attack_of_the_Giant_Leeches.avi - Add New Torrent
Save As
Torrent Contents
Select All
Select None
Advanced...
Cancel
OK
Add
Add URL
Add Feed
Start
Stop
Completed
Active
Uploaded
Status:
GENERAL
Save As:
Total Size:
Hash:
Reach Millions of People with a Self Serve Ad

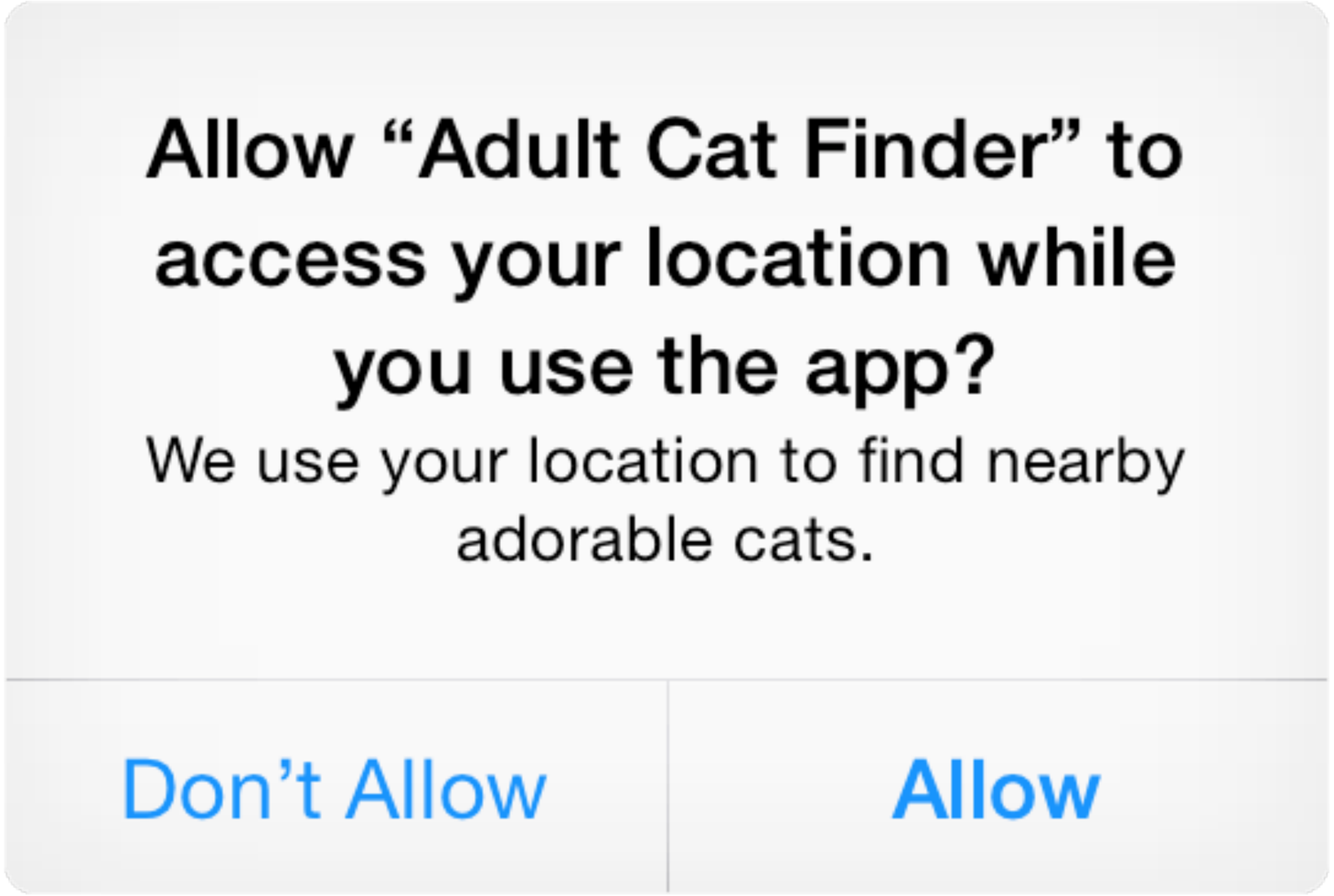

What does this program *need* to be able to do?
Maybe:
access screen
manage a directory of downloaded files
access config & documentation files
open connections for a given set of protocols
receive connections as a server
Attack_of_the_Giant_Leeches.avi - Add New Torrent
Add
Add URL
Add Feed
Start
Stop
Save As
Torrent Contents
Completed
Active
Uploaded
Save As:
Total Size:
Created O
Hash:
Advanced...
Cancel
OK
a Self Serve Ad

Check for Understanding

- We've seen that laptop/desktop platforms grant applications a lot of privileges

- Quiz: Name a platform that does a better job of least privilege

Does this follow the principle of least privilege?



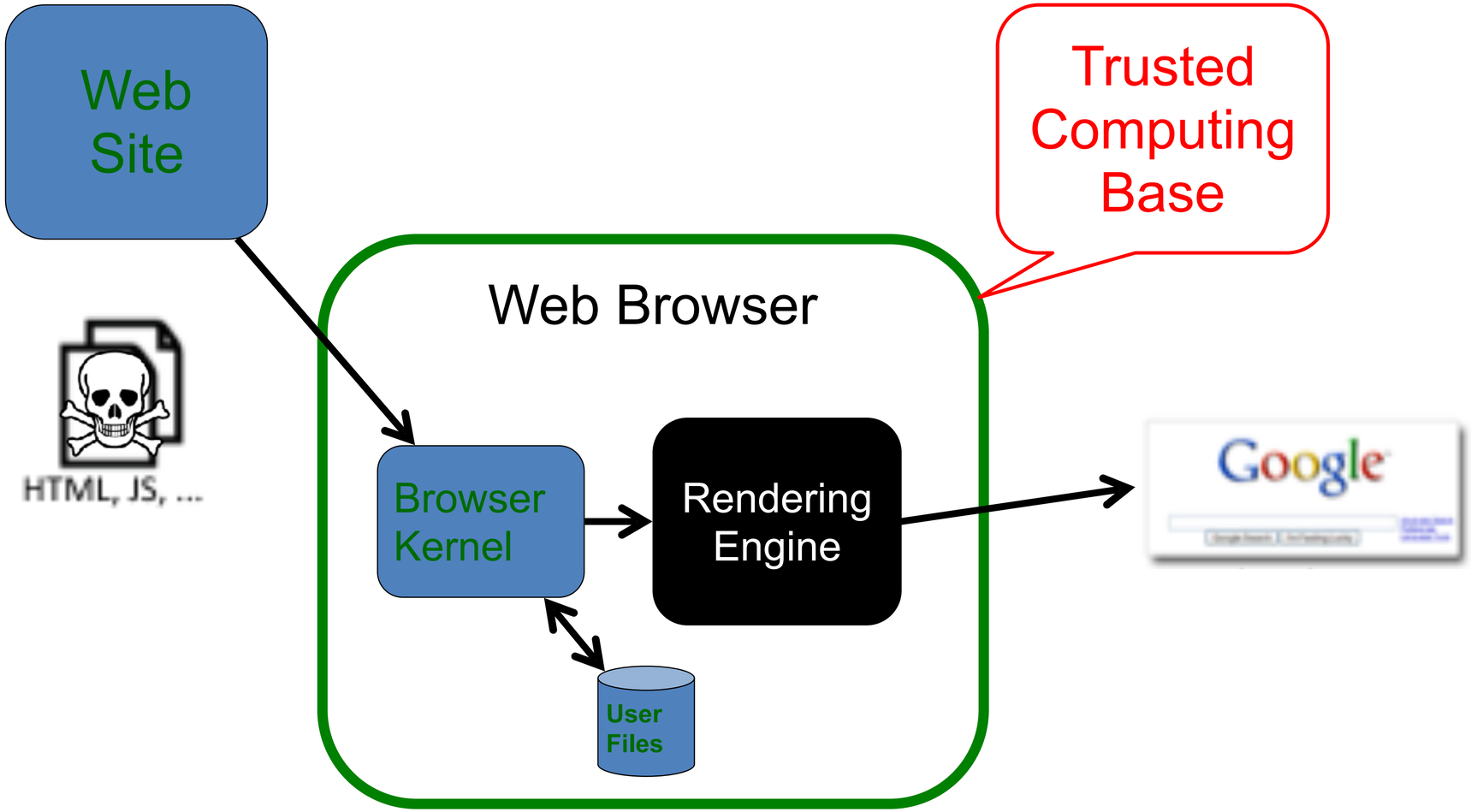
Thinking About Least Privilege

- When assessing the security of a system's design, identify the Trusted Computing Base (TCB).
  - What components does security ***rely upon***?
- Security requires that the TCB:
  - Is correct
  - Is complete (can't be bypassed)
  - Is itself secure (can't be tampered with)
- Best way to be assured of correctness and its security?
  - KISS = Keep It Simple, Stupid!
  - Generally, Simple = Small
- One powerful design approach: privilege separation
  - Isolate privileged operations to as small a component as possible

The Base for Isolation: The Operating System...

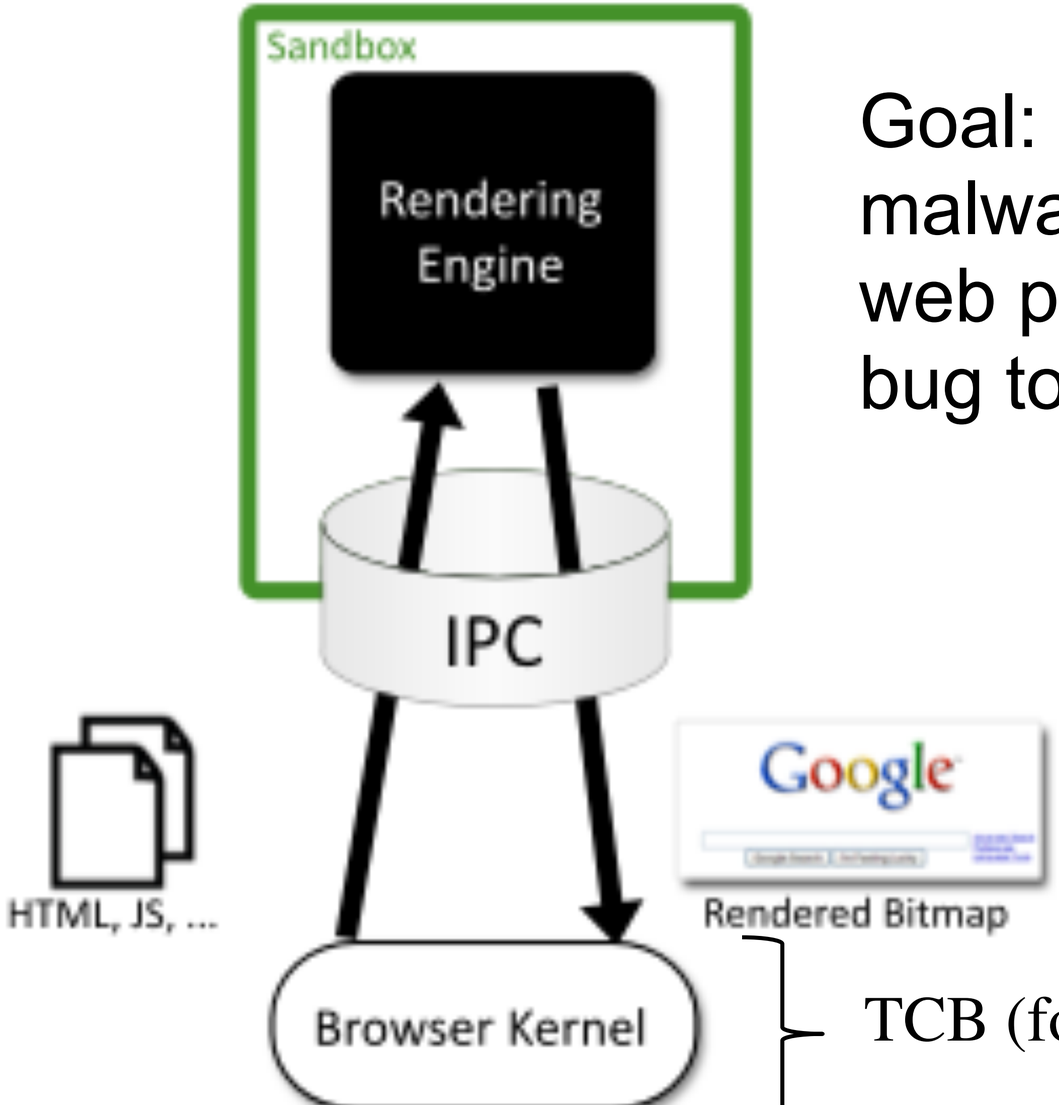
- The operating system provides the following "guarantees"
  - Isolation: A process can not access (read OR write) the memory of any other process
  - Permissions: A process can only change files etc if it has permission to
    - This ***usually*** means "Anything that the user can do" in something like Windows or MacOS
      - It can be considerably less in Android or iOS
    - But even in Windows, MacOS, & Linux one can say "I don't want any permissions"

Web browser



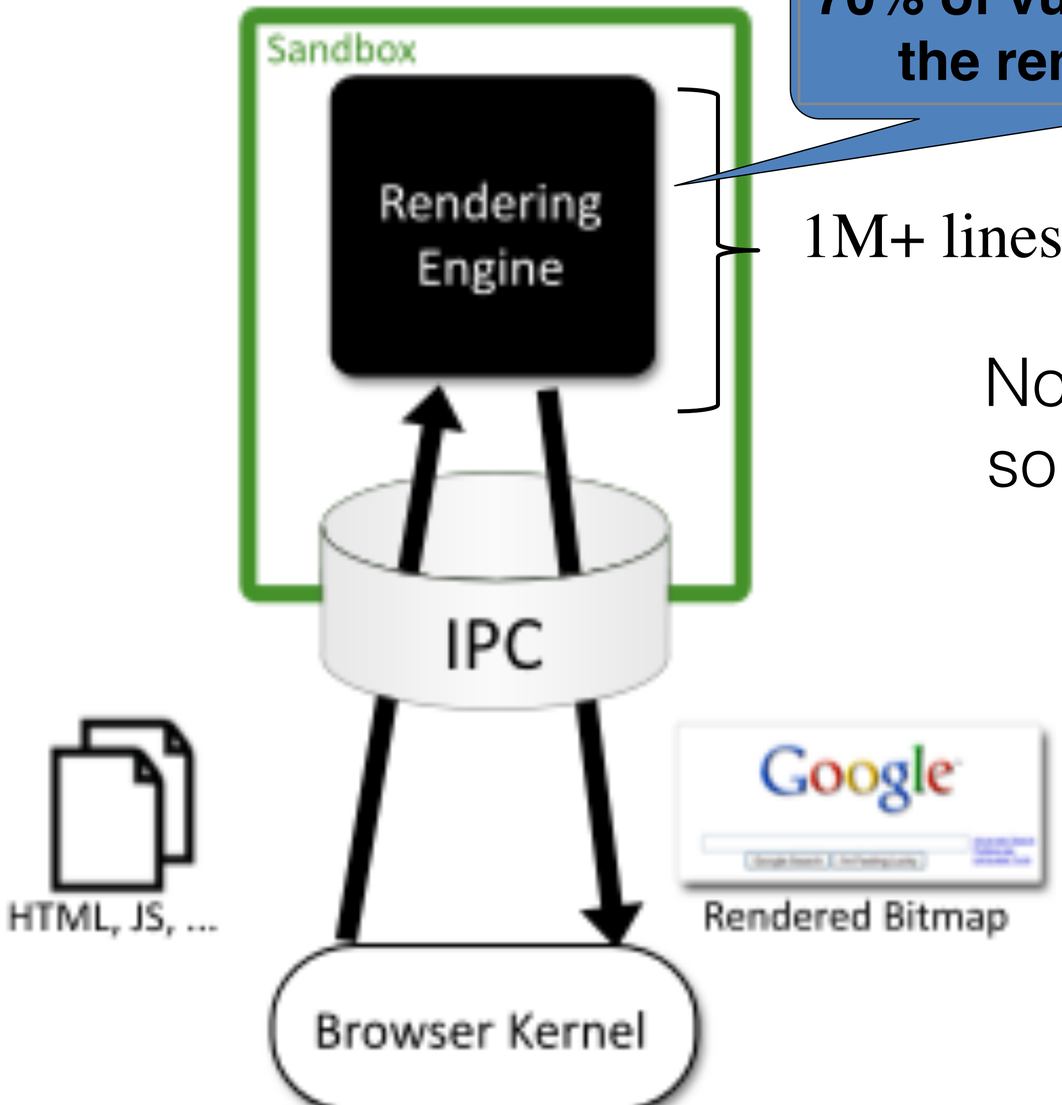
"Drive-by malware": malicious web page exploits browser bug to infect local files

The Chrome browser



Goal: prevent “drive-by malware”, where a malicious web page exploits a browser bug to infect local files

The Chrome browser



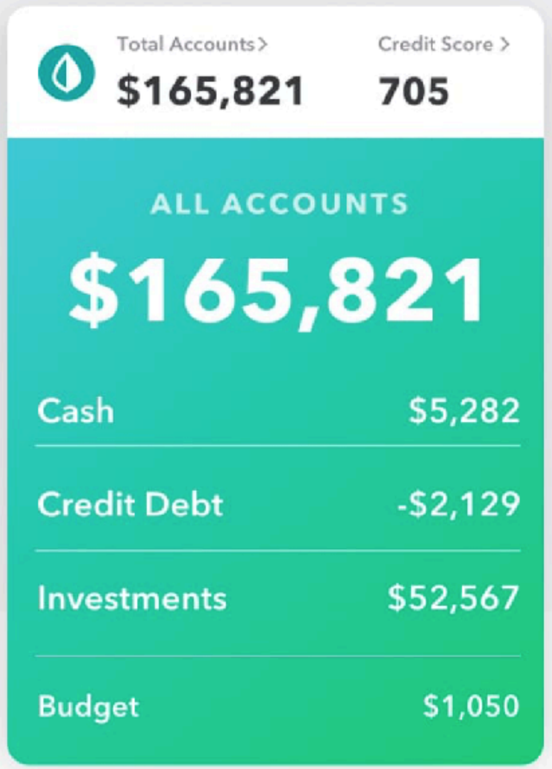
70% of vulnerabilities are in the rendering engine.

1M+ lines of code

Now it sandboxes ***each web context*** so you can't even read out other web page content (E.g. spectre)

intuit mint

Sign up | Sign in



All your money in one place

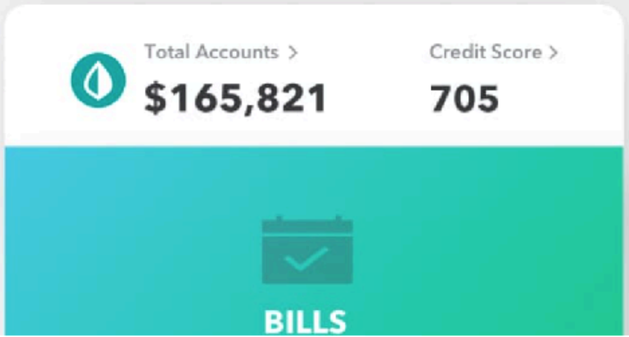
We bring together all of your accounts, bills and more, so you can conveniently manage your finances from one dashboard.

- See all of your bills and money at a glance
- Create budgets easily with tips tailored to you
- Enjoy access to unlimited free credit scores, without harming your credit

Sign Up Free

Effortlessly stay on top of bills

Bills are now easier than ever to track. Simply add them to your dashboard to see and monitor them all at once.



Privacy Settings

3

Discuss with a partner

- How would you architect mint.com to reduce the likelihood of a breach that reveals everyone's bank passwords?

- How would you architect mint.com to reduce the likelihood of a breach that empties everyone's bank account?

Ensuring Complete Mediation

- To secure access to some capability/resource, construct a ***reference monitor***
- Single point through which all access must occur
  - E.g.: a network firewall
- Desired properties:
  - Un-bypassable (“complete mediation”)
  - Tamper-proof (is itself secure)
  - Verifiable (correct)
  - (Note, just restatements of what we want for TCBs)
- One subtle form of reference monitor flaw concerns race conditions …

A Failure of Complete Mediation

More security principles

- Use fail-safe defaults
- Consider human factors
- Only as secure as the weakest link
- Don’t rely on security through obscurity
- Trusted path

Leitura de código de barras

Bradesco
Tarifas de
Serviços Bancários
Multi Expresso

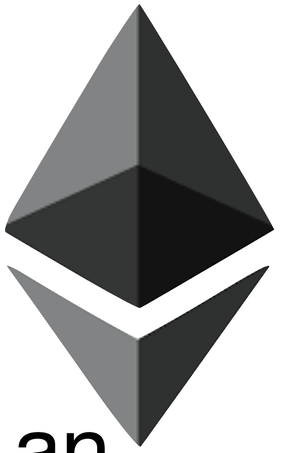
Time of Check to Time of Use Vulnerability: Race Condition


```
procedure withdraw(w)
   // contact central server to get balance
   1. let b := balance

   2. if b < w, abort

   // contact server to set balance
   3. set balance := b - w

   4. dispense $w to user
```

Suppose that *here* an attacker arranges to suspend first call, and calls withdraw again **concurrently**

TOCTTOU = Time of Check To Time of Use

A Hundred Million Dollar TOCTTOU Bug...



- Ethereum is a cryptocurrency which offers "smart" contracts
  - Program you money in a language that makes JavaScript and PHP look beautiful and sane
- The DAO (Distributed Autonomous Organization) was an attempt to make a distributed mutual fund in Ethereum
  - Participants could vote on "investments" that should be made
- The DAO supported withdrawals as well

A "Feature" In The Smart Contract

- To withdraw, the code was:
  - Check the balance, then send the money, then decrement the balance
- But sending money in Ethereum can send to ***another program written by the recipient***
- So someone "invested", then did a withdraw to his program
  - Which would initiate another withdraw...