Side-channel-leaks in Web Applications: A Reality today, A Challenge Tomorrow

Shuo Chen,Rui Wang, XiaoFeng Wang and Kehuan Zhang

PC App vs. Web App

Traditional PC application

Web application

(1) split between client and server
(2) state transitions driven by network traffic

Worry about privacy?
Let’s do encryption.

Side-Channel Leaks

- The eavesdropper cannot see the contents, but can observe :
  - number of packets, timing/size of each packet

- Previous research showed privacy issues in various domains:
  - SSH, voice-over-IP, video-streaming, anonymity channels (e.g., Tor)

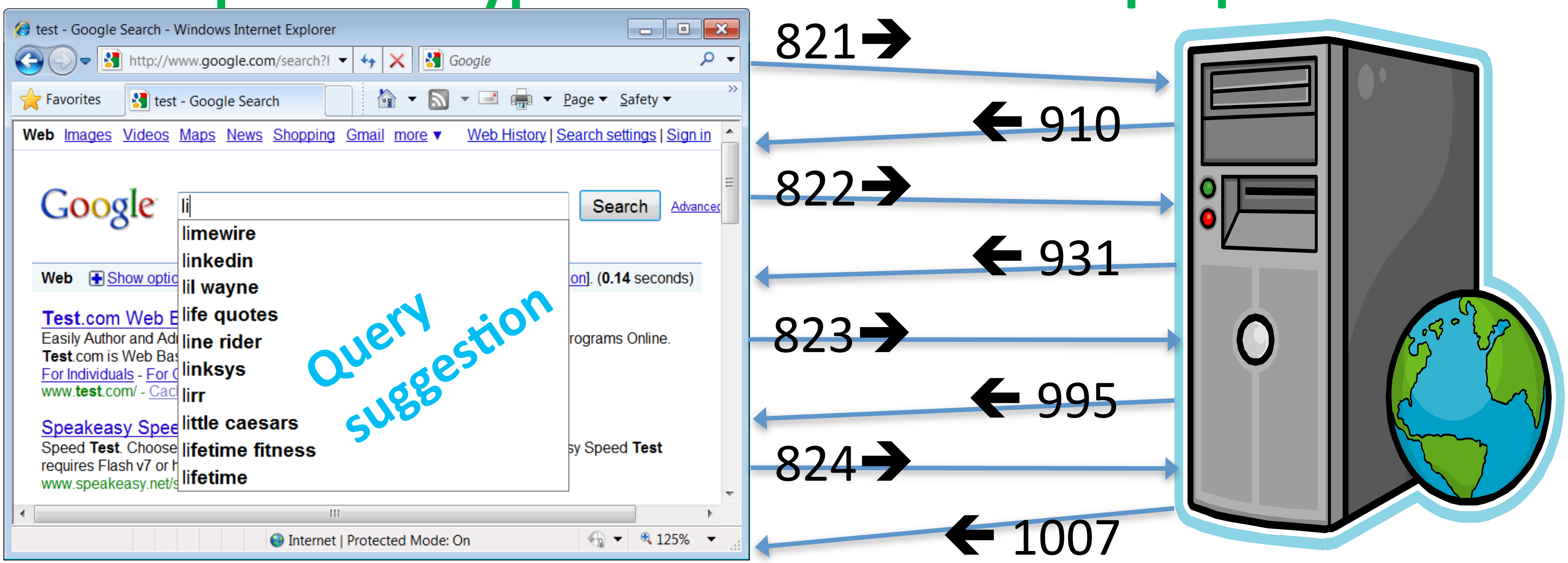
- Our motivation and target domain:
  - target: today's web applications
  - motivation: Software-as-a-Service (SaaS) becomes mainstream, and the web is the platform to deliver SaaS apps.

Our Main Findings

- Surprisingly detailed user information is being leaked out from several high-profile web applications
  - personal health data, family income, investment details, search queries
  - (Anonymized app names per requests from related companies)
- The root causes are some fundamental characteristics in today's web apps
  - stateful communication, low entropy input and significant traffic distinctions.
- Defense is non-trivial
  - effective defense needs to be application specific.
  - calls for a disciplined web programming methodology.

Scenario: search using encrypted Wi-Fi WPA/WPA2.

Example: user types "*list*" on a WPA2 laptop.



Attacker's effort: linear, not exponential.

Consequence: Anybody on the street knows our search queries.

OnlineHealth[A] ("A" denoting a pseudonym)

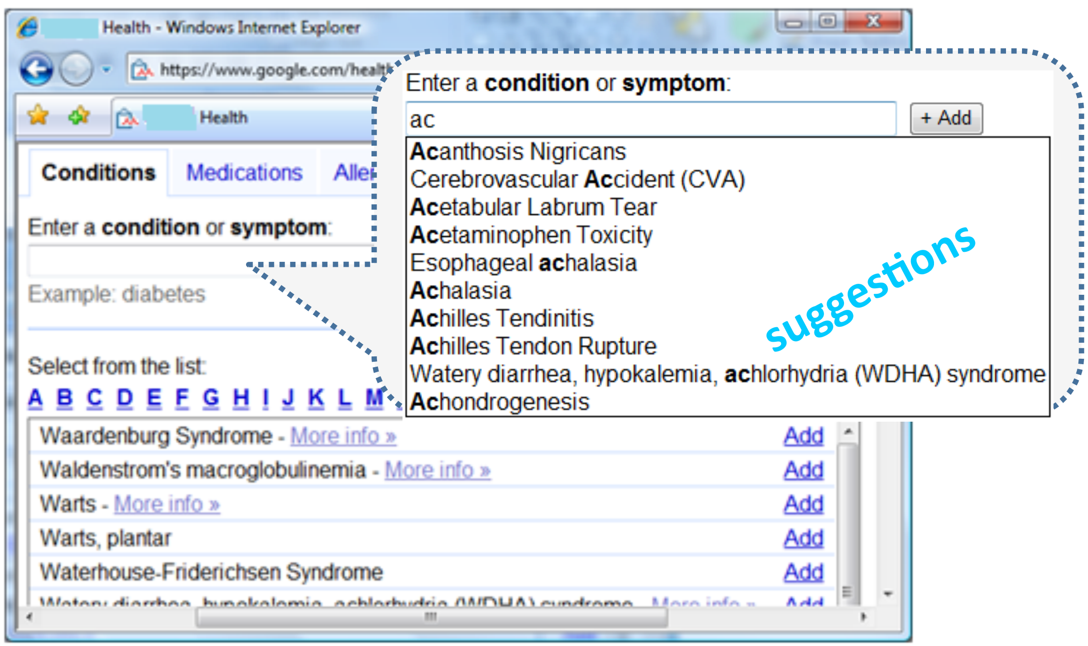
- A web application by one of the most reputable companies of online services

- Illness/medication/surgery information is leaked out, as well as the type of doctor being queried.

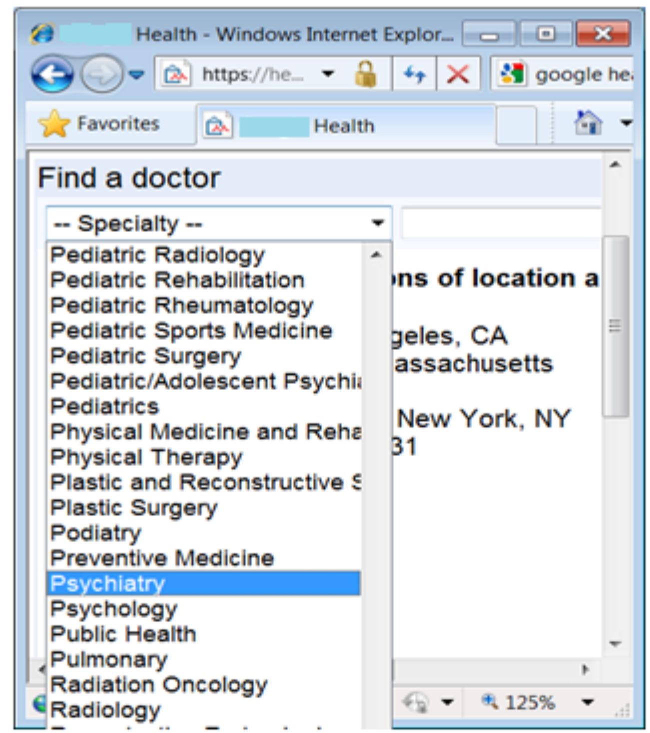
- Vulnerable designs
- Entering health records
    - By typing – auto suggestion
    - By mouse selecting – a tree-structure organization of elements
- Finding a doctor
    - Using a dropdown list item as the search input

Attacker's power

Entering health records: no matter keyboard typing or mouse selection, attacker has a 2000× ambiguity reduction power.



Find-A-Doctor: attacker can uniquely identify the specialty.



OnlineTax^A

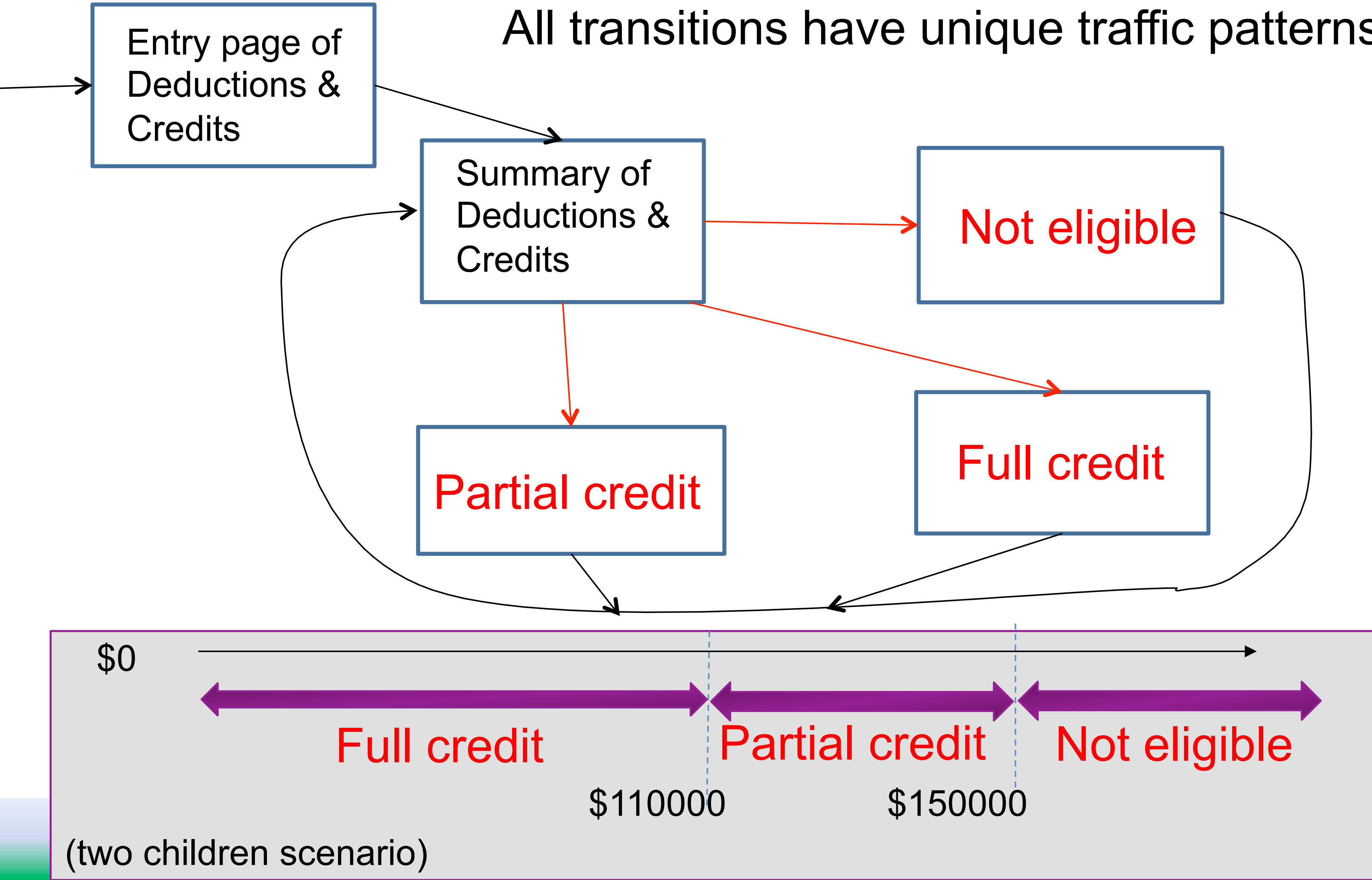
- It is the online version of one of the most widely used applications for the U.S. tax preparation.

- Design: a wizard-style questionnaire
  - Tailor the conversation based on user's previous input.

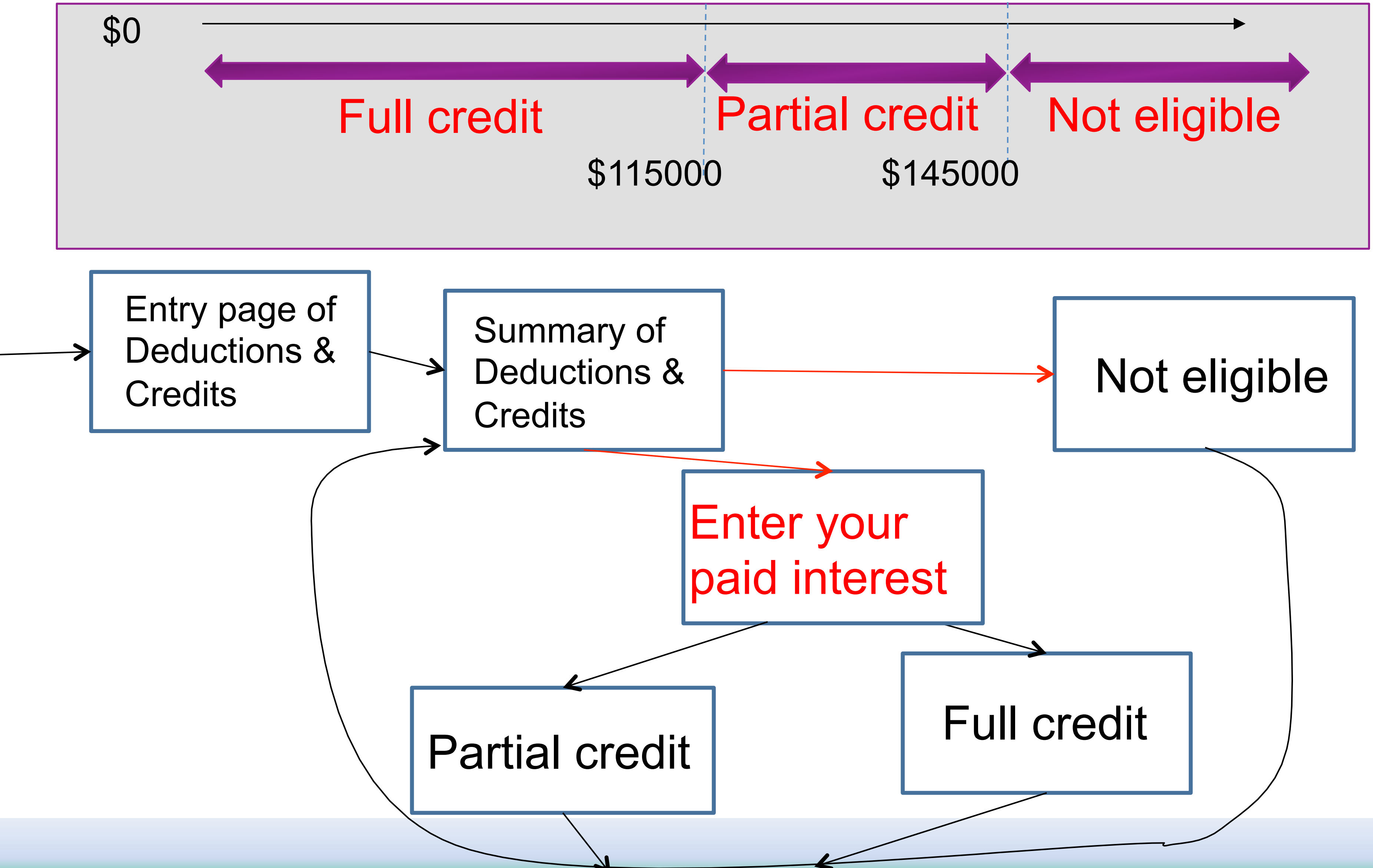
  - The forms that you work on tell a lot about your family
  - Filing status
  - Number of children
  - Paid big medical bill
  - The adjusted gross income (AGI)

child credit state machine

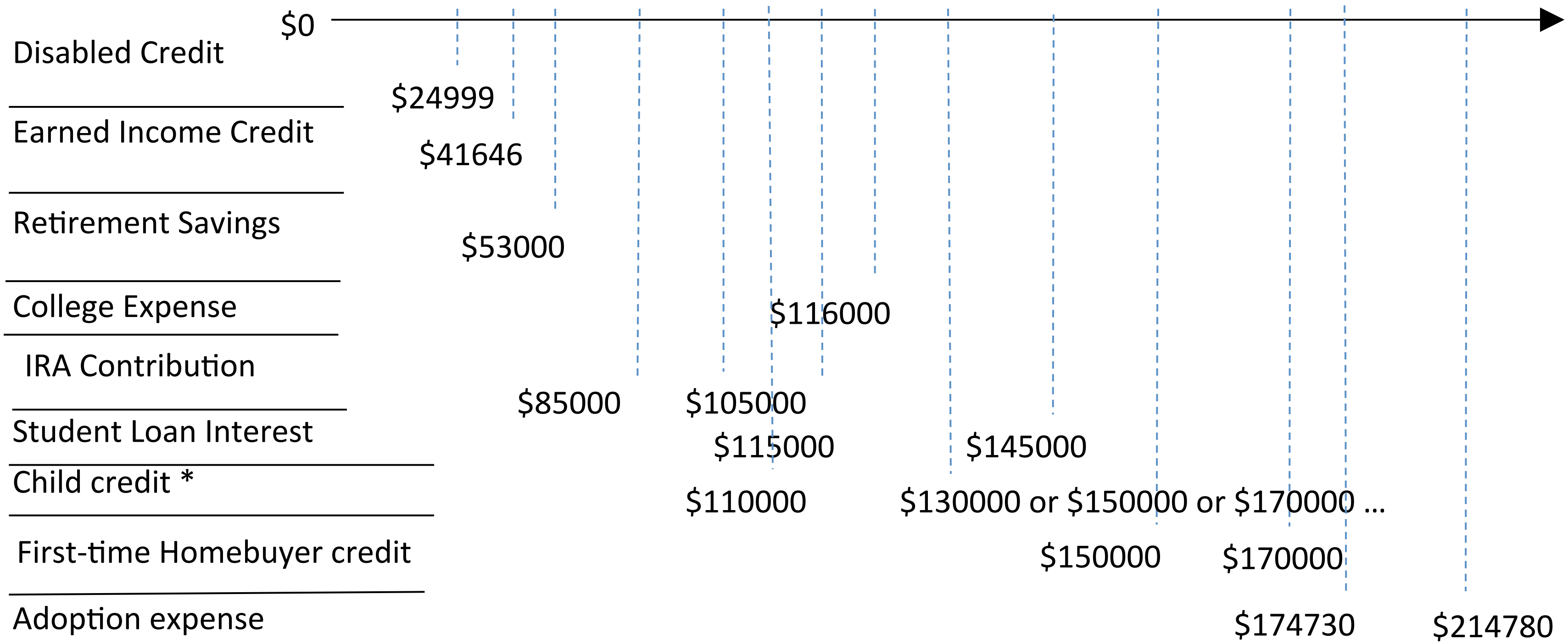
All transitions have unique traffic patterns.



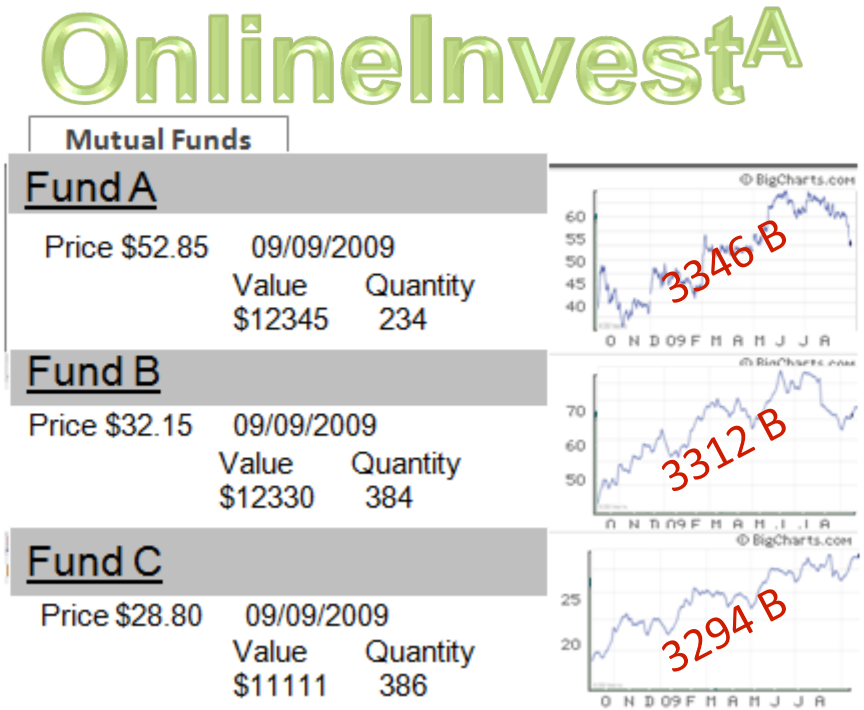
Student-loan-interest credit



A subset of identifiable AGI thresholds



- **We are not tax experts.**
- **OnlineTax[A] can find more than 350 credits/deductions.**



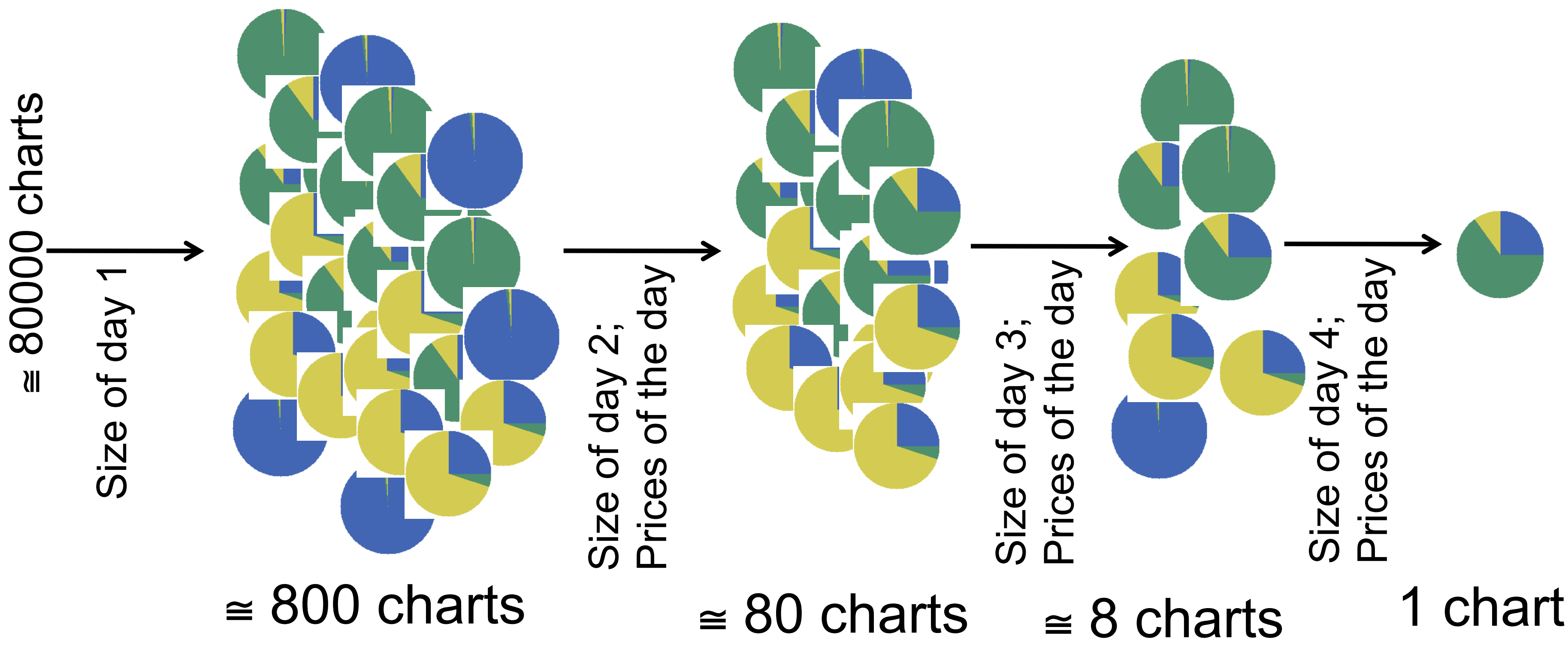
A major financial institution in the U.S.

Which funds you invest?

- No secret.
- Each price history curve is a GIF image from MarketWatch.
- Everybody in the world can obtain the images from MarketWatch.
- Just compare the image sizes!

Inference based on the evolution of the pie-chart size in 4-or-5 days

- The financial institution updates the pie chart every day after the market is closed.
- The mutual fund prices are public knowledge.



Root causes: some fundamental characteristics of today's web applications

Fundamental characteristics of web apps

- Significant traffic distinctions
  - The chance of two different user actions having the same traffic pattern is really small.
  - Distinctions are everywhere in web app traffic. It's the norm.
- Low entropy input
  - Eavesdropper can obtain a non-negligible amount of information
- Stateful communication
  - Many pieces of non-negligible information can be correlated to infer more substantial information
  - Often, multiplicative ambiguity reduction power!

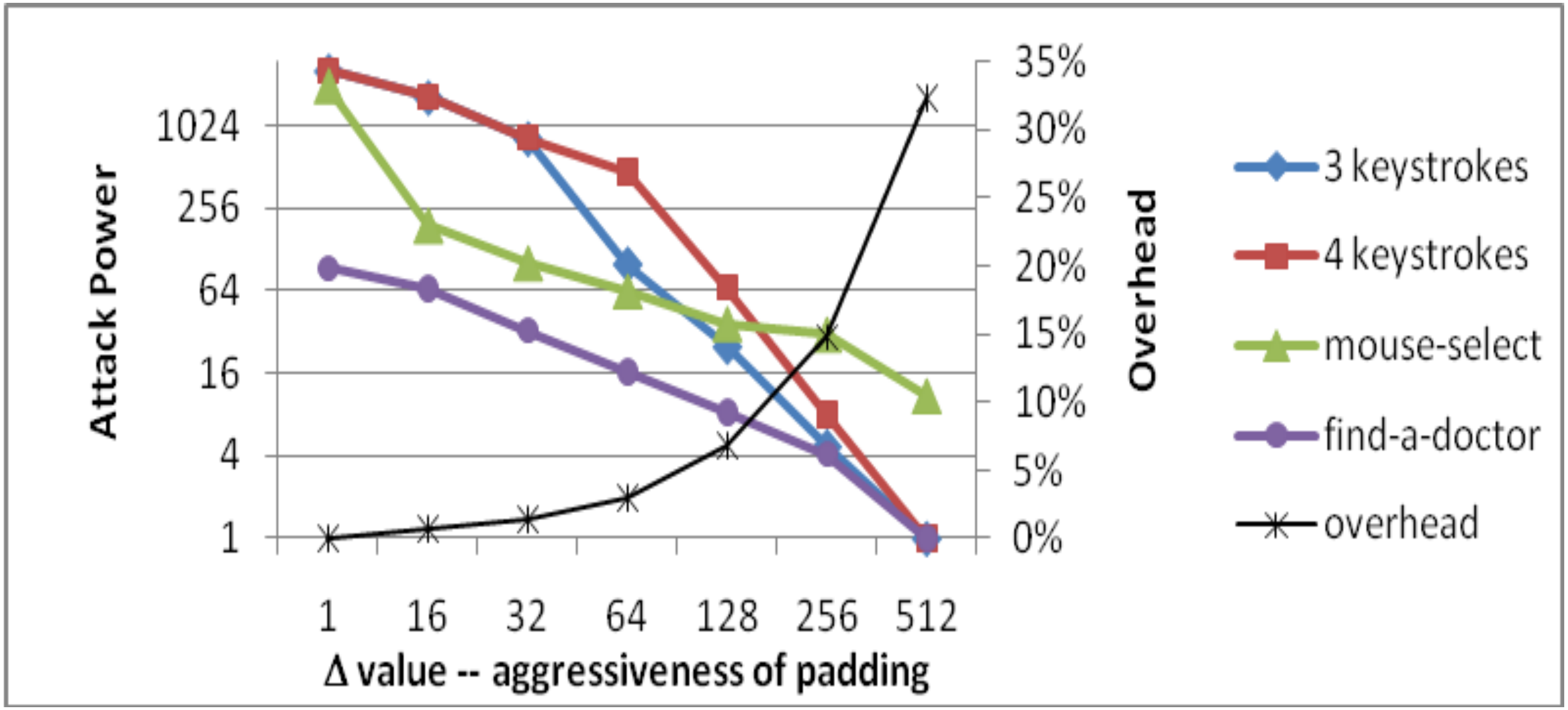
Challenging to Mitigate the Vulnerabilities

Why challenging?

- Traffic differences are everywhere. Which ones result in serious data leaks?
  - Need to analyze the application semantics, the availability of domain knowledge, etc.
  - Hard.
- Is there a vulnerability-agnostic defense to fix the vulnerabilities without finding them?
  - Obviously, padding is a must-do strategy.
    - Packet size rounding: pad to the next multiple of Δ
    - Random-padding: pad x bytes, and $x \in [0, \Delta)$
  - We found that even for the discussed apps, the defense policies have to be case-by-case.

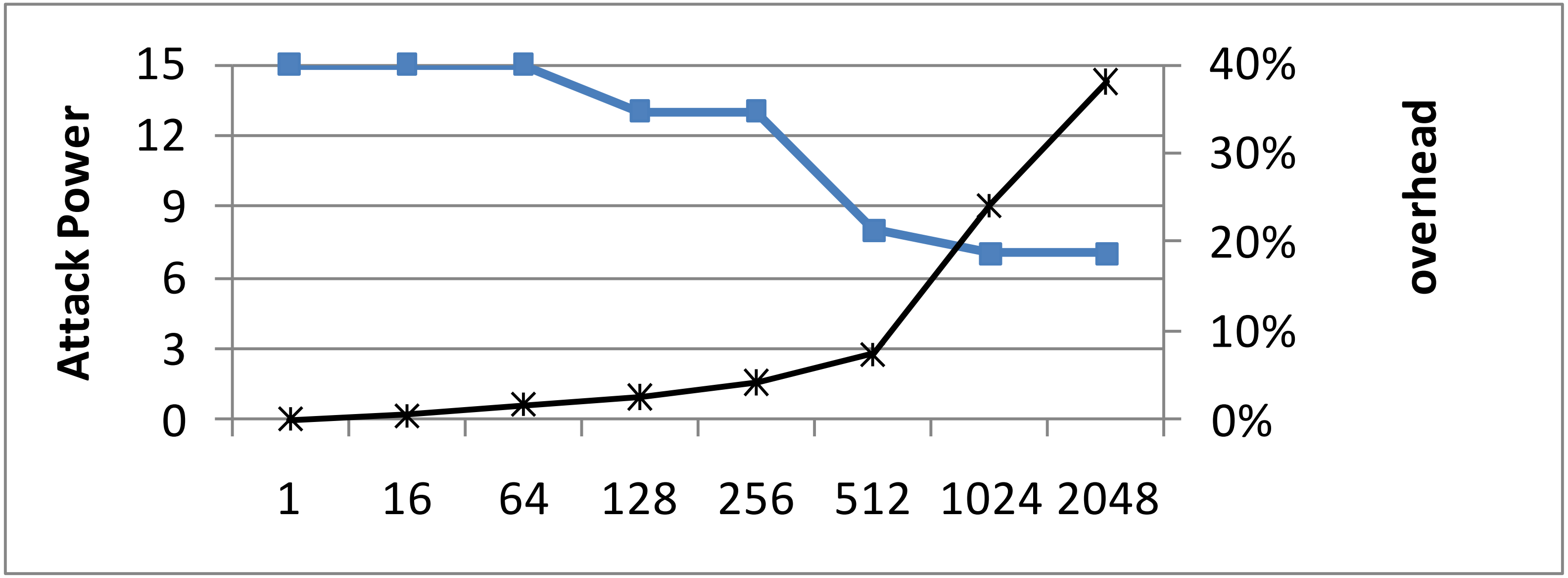
Vulnerability-agnostic padding for OnlineHealth[A]

- OK to use rounding or random-padding
- 32.3% network overhead (i.e., 1/3 bandwidth on side-channel info hiding)



Vulnerability-agnostic padding for OnlineTax[A]

- Neither rounding nor random-padding can solve the problem.
  - Because of the asymmetric path situation



Vulnerability-agnostic padding for OnlineInvest^{A}

- Random padding is not appropriate, because
  - Repeatedly applying a random padding policy to the same responses will quickly degrade the effectiveness.
    - Suppose the user checks the mutual fund page for 7 times, then
      - 96% probability that the randomness shrinks to $\Delta/2$.

- OnlineInvest^{A} cannot do the padding by itself
  - Because the browser loads the images from MarketWatch.

SaaS and Cloud-Computing

Google

Operating System

Need to develop a disciplined methodology for side-channel-info hiding

Conclusions

- Side-channel-leaks are a serious threat to user privacy in the era of SaaS.
- Defense must be vulnerability-specific, and thus non-trivial.
- Call for future research on the programming practice for protecting online privacy.