UNDERGROUND ECONOMIES

CMSC 414

MAY 10 2018

BUT FIRST:
APPLICATION-LAYER SECURITY

APPLICATION LAYER

- Familiar faces:
  - HTTP (web), SMTP (mail), Skype, Bittorrent, Gaming, …
- All of these choose explicitly from the layer beneath them (UDP vs TCP)
  - TCP when you must have reliable, in-order delivery
    - Web, mail, BitTorrent
  - UDP when you prefer timeliness over reliability
    - Gaming, Skype

IN WHAT LAYER SHOULD SECURITY GO?

- Fundamental principle: the **end-to-end principle** (applies to reliability in general)

- If there is a function that can be implemented correctly and completely only at the end hosts, then put it there, not in the network.
  - Exception: the network can be used as a performance enhancement

- How can TCP know what it means to secure your application?
  - Does it just need encryption? Key sharing? Obfuscated timing? ….?

EXAMPLE: SMTP (RFC 821)

Example of the SMTP Procedure

This SMTP example shows mail sent by Smith at host Alpha.ARPA,
to Jones, Green, and Brown at host Beta.ARPA. Here we assume
that host Alpha contacts host Beta directly.

```
S: MAIL FROM:<Smith@Alpha.ARPA>
R: 250 OK

S: RCPT TO:<Jones@Beta.ARPA>
R: 250 OK

S: RCPT TO:<Green@Beta.ARPA>
R: 550 No such user here

S: RCPT TO:<Brown@Beta.ARPA>
R: 250 OK

S: DATA
R: 354 Start mail input; end with <CRLF>.<CRLF>
S: Blah blah blah...
S: ...etc. etc. etc.
S: <CRLF>.<CRLF>
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The mail has now been accepted for Jones and Brown. Green did
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                        Example 1

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These are all just packets and you can construct whatever packets you want

IN WHAT LAYER SHOULD SECURITY GO?

- Need to understand what properties you get from each layer

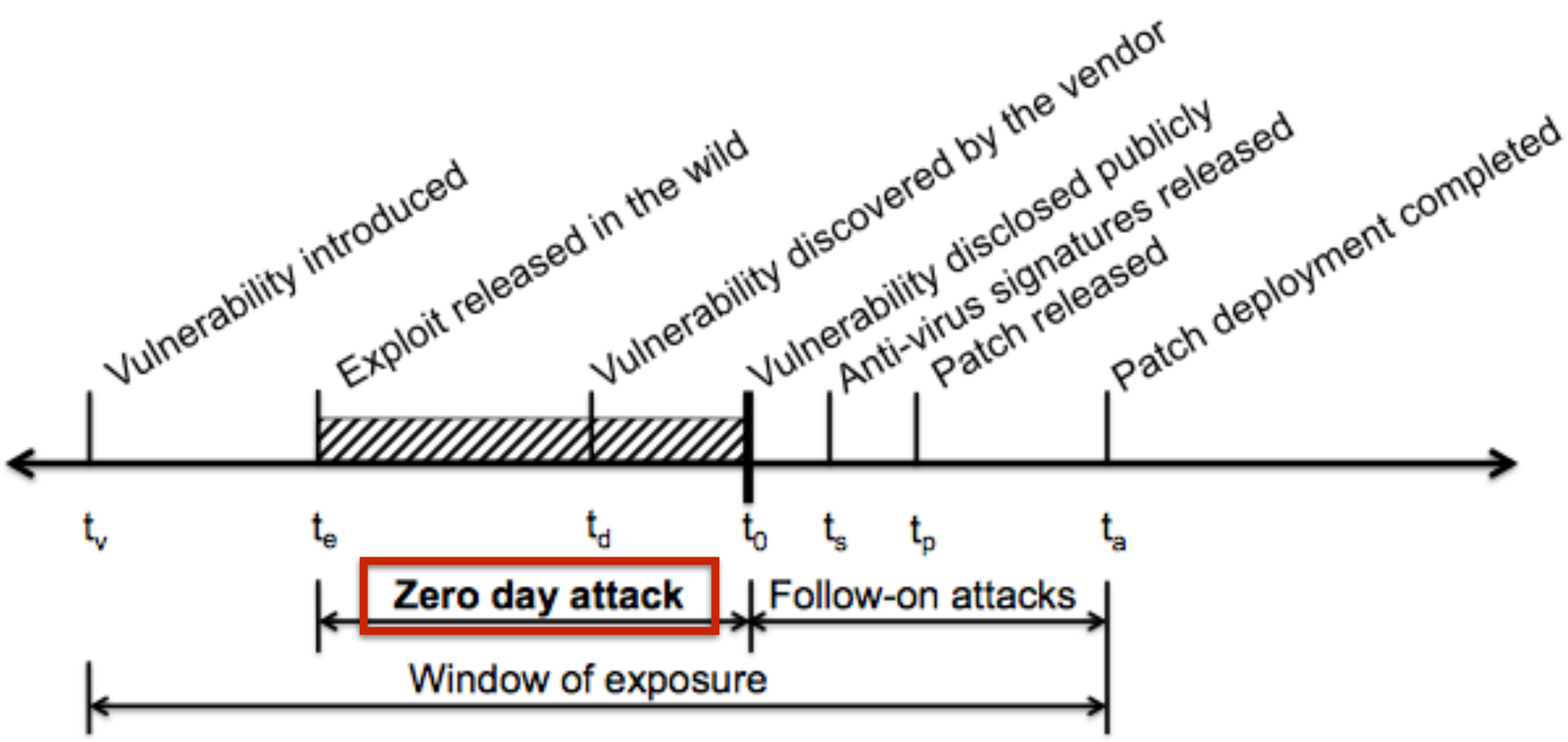
- If you require a property that cannot be guaranteed by the underlying layers, then you have to add it to the “end”

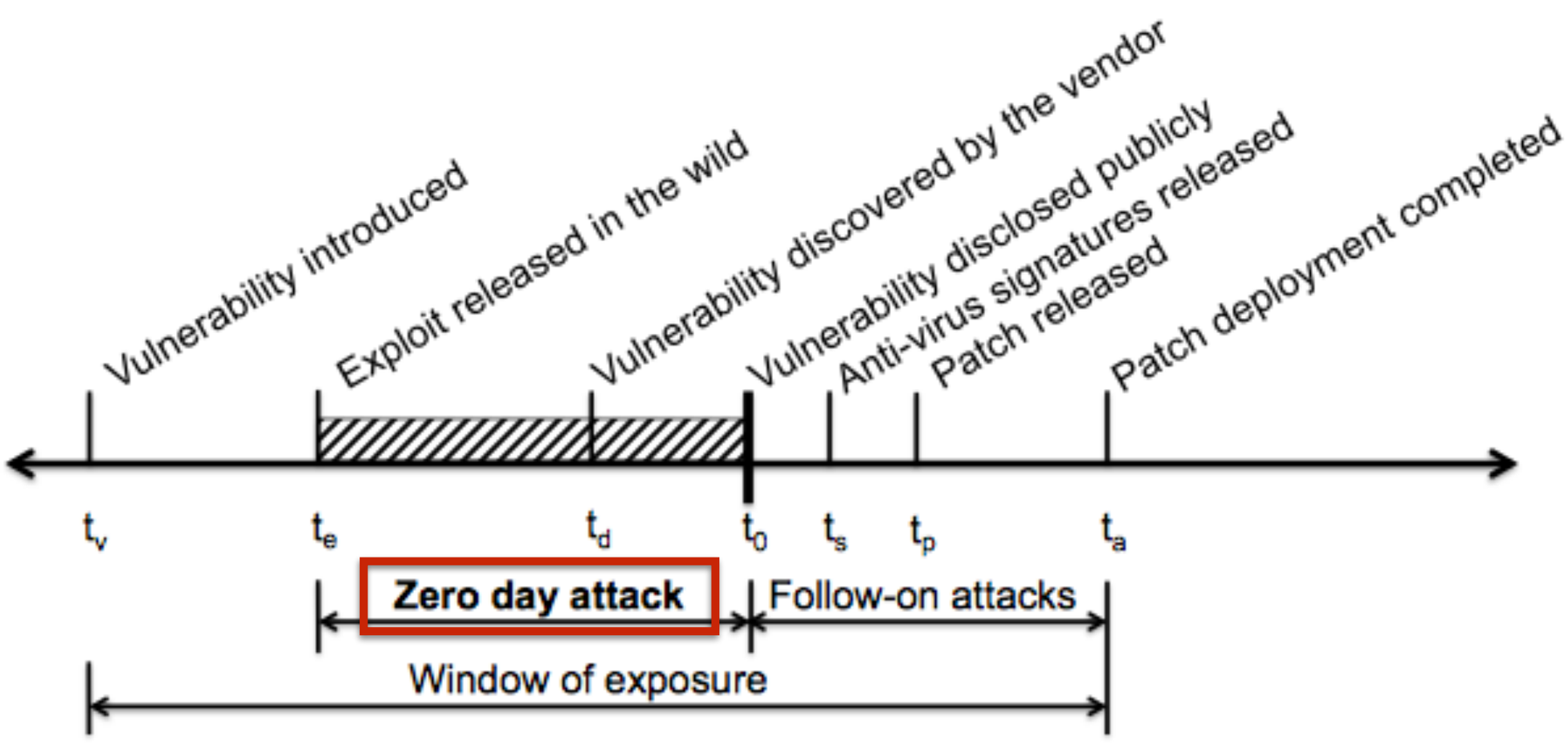
- Email: how would you fix this?
  - You want authentic communication
  - Can you build it out of an unauthenticated channel?

UNDERGROUND
ECONOMIES

UNDERGROUND ECONOMIES

- Economics drives both the attacks and the defenses
- What is for sale? Who sells it? How?
  - Defenders: Antivirus vendors, firewall vendors, etc.
  - *What about the attackers?*
- The idea is that we may be able to stem attacks if we can understand
  - the incentives
  - the choke points (might there be one bank we could shut down to cease spam?)

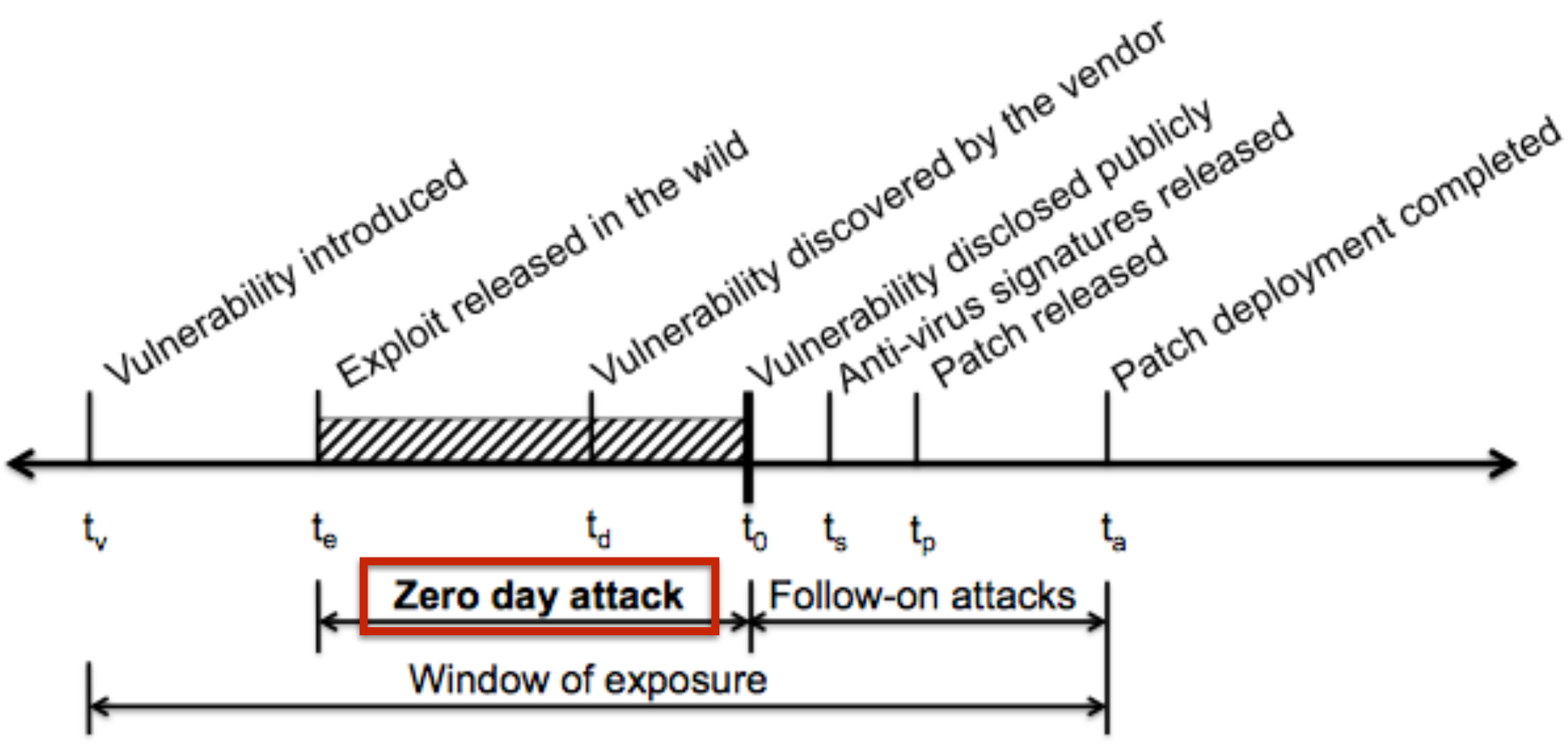

Vulnerability introduced
Exploit released in the wild
Vulnerability discovered by the vendor
Vulnerability disclosed publicly
Anti-virus signatures released
Patch released
Patch deployment completed
t_v
t_e
t_d
t_0
t_s
t_p
t_a
Zero day attack
Follow-on attacks
Window of exposure



- **Who buys**: Attackers, spies (and the companies who wrote the software) want to know about them

- **Through whom**: anonymous middlemen (e.g. Grusq) who match vulnerability finders up with buyers. Take commission (15% typical).

- **Payment**: Made in installments (cease payment when zero-day over)



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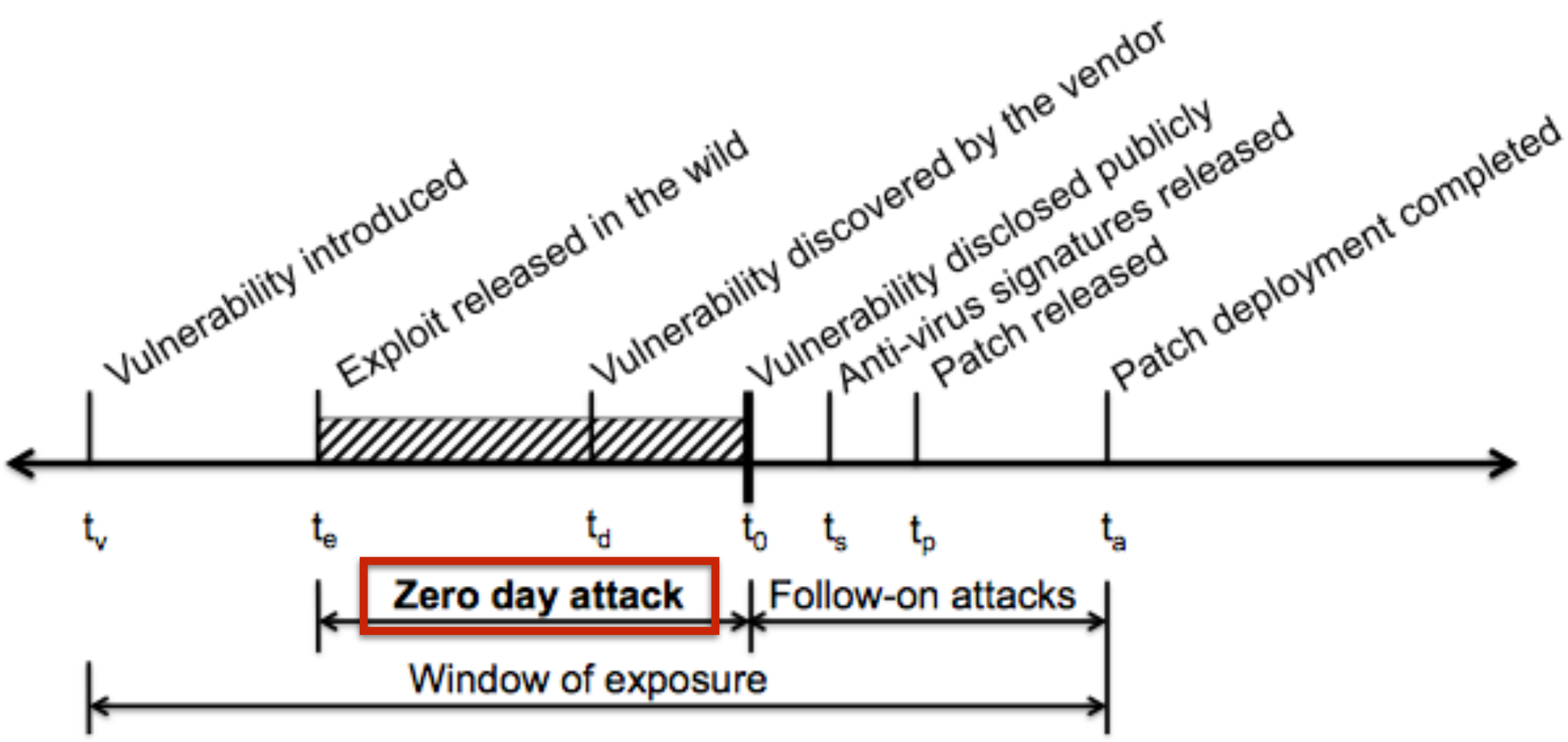

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ADOBE READER	$5,000–$30,000
MAC OSX	$20,000–$50,000
ANDROID	$30,000–$60,000
FLASH OR JAVA BROWSER PLUG-INS	$40,000–$100,000
MICROSOFT WORD	$50,000–$100,000
WINDOWS	$60,000–$120,000
FIREFOX OR SAFARI	$60,000–$150,000
CHROME OR INTERNET EXPLORER	$80,000–$200,000
IOS	$100,000–$250,000

"Shopping for zero-days" Forbes 2012

BUG BOUNTY PROGRAMS

ZERODIUM Payouts for Desktops/Servers*

Windows
macOS
Linux
Any OS

RCE: Remote Code Execution
LPE: Local Privilege Escalation
SBX: Sandbox Escape or Bypass
VME: Virtual Machine Escape

Up to $300,000										1.001 Win RCE Zero Click (Win)
Up to $150,000								4.001 Chrome RCE+LPE (Win)	2.001 Apache RCE (Linux)	2.002 MS IIS RCE (Win)
Up to $100,000				5.001 MS Outlook RCE (Win)	4.002 Firefox+Tor RCE+LPE (Linux)	4.003 Flash RCE+LPE (Win)	2.003 OpenSSL RCE (Linux)	2.004 PHP RCE (Linux)	3.001 MS Exchange RCE (Win)	
Up to $80,000	6.001 VMware ESXi VME (Win/Linux)		5.002 Adobe PDF RCE+LPE (Win)	5.003 Thunderbird RCE (Win/Linux)	4.004 Firefox+Tor RCE+LPE (Win)	4.005 Flash RCE w/o SBX (Win)	4.006 Chrome RCE+LPE (Linux/Mac)	4.007 Edge RCE+LPE (Win)	4.008 Safari RCE+LPE (Mac)	
Up to $50,000	6.002 VMware WS VME (Win/Linux)	7.001 Antivirus RCE (Win)	5.004 Word/Excel RCE (Win)	5.005 Windows PDF RCE (Win)	4.009 Chrome RCE w/o SBX (Win/Linux/Mac)	3.002 Sendmail RCE (Linux)	3.003 Postfix RCE (Linux)	3.004 Dovecot RCE (Linux)	8.001 WordPress RCE (Linux)	
Up to $30,000	6.003 USB LPE (Win/Mac)			6.004 Linux LPE (Linux)	6.005 macOS LPE/SBX (Mac)	6.006 Windows LPE/SBX (Win)	4.010 Firefox+Tor RCE w/o SBX (Win/Linux/Mac)	4.011 Edge RCE w/o SBX (Win)	4.012 Safari RCE w/o SBX (Mac)	
Up to $10,000	7.002 Antivirus LPE (Win)	8.002 IPS Suite RCE (Linux)	8.003 phpBB RCE (Linux)	8.004 vBulletin RCE (Linux)	8.005 MyBB RCE (Linux)	8.006 Joomla RCE (Linux)	8.007 Drupal RCE (Linux)	8.008 Roundcube RCE (Linux)	8.009 Horde RCE (Linux)	9.001 Routers RCE

** All payouts are subject to change or cancellation without notice, at the discretion of ZERODIUM. All trademarks are the property of their respective owners.*

BUG BOUNTY PROGRAMS

ZERODIUM Payouts for Mobiles*

RJB: Remote Jailbreak with Persistence
RCE: Remote Code Execution
LPE: Local Privilege Escalation
SBX: Sandbox Escape or Bypass

iOS
Android
Any OS

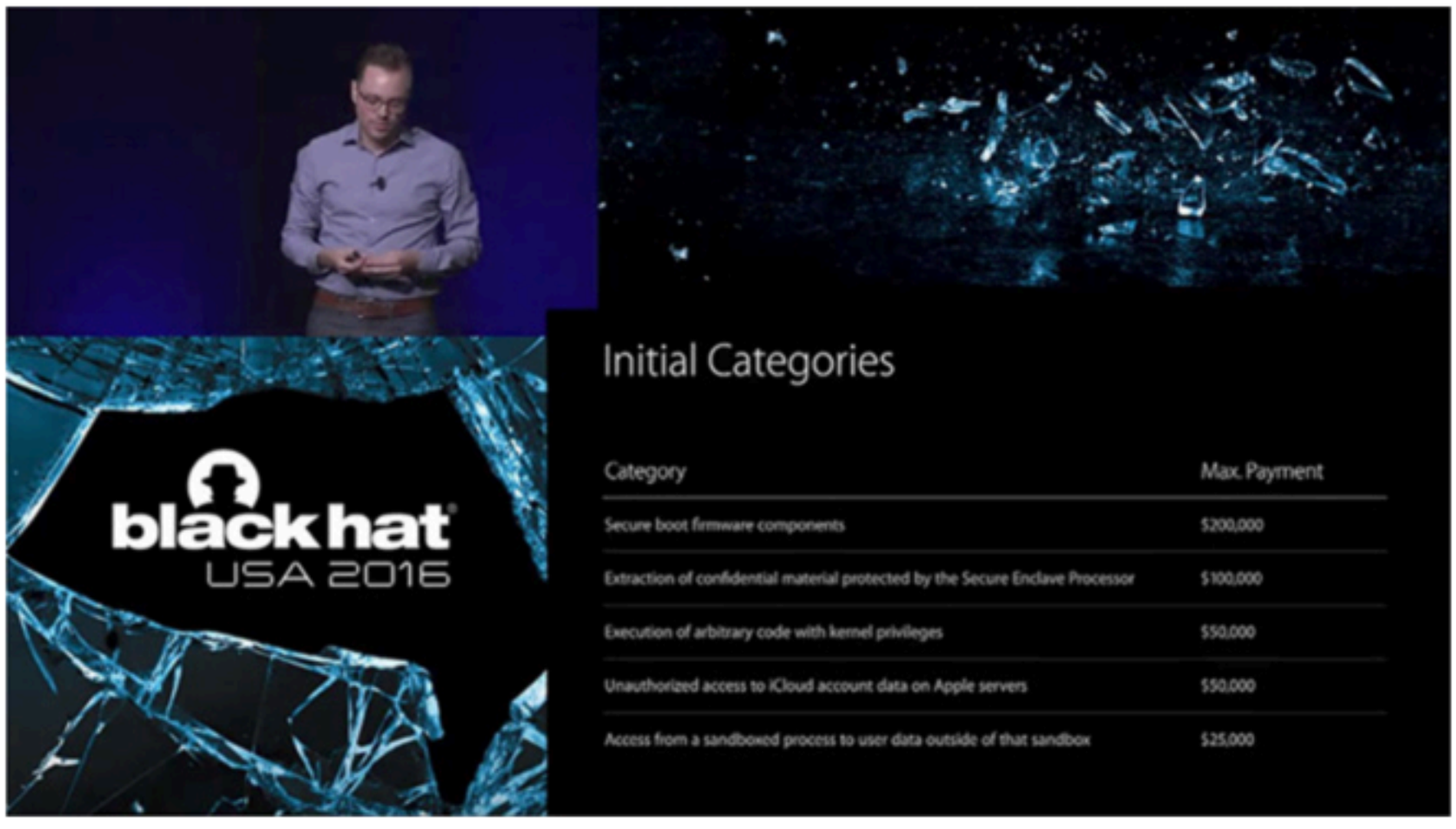
Up to $1,500,000										1.001 iPhone RJB Zero Click iOS
Up to $1,000,000										1.002 iPhone RJB iOS
Up to $500,000	2.001 WeChat RCE+LPE iOS/Android	2.002 Viber RCE+LPE iOS/Android		2.003 FB Messenger RCE+LPE iOS/Android	2.004 Signal RCE+LPE iOS/Android	2.005 Telegram RCE+LPE iOS/Android	2.006 WhatsApp RCE+LPE iOS/Android	2.007 iMessage RCE+LPE iOS	2.008 SMS/MMS RCE+LPE iOS/Android	2.009 Email App RCE+LPE iOS/Android
Up to $150,000	3.001 Baseband RCE+LPE iOS/Android						2.010 Media Files RCE+LPE iOS/Android	2.011 Documents RCE+LPE iOS/Android	4.001 Chrome RCE+LPE iOS/Android	4.002 Safari RCE+LPE iOS
Up to $100,000	5.001 Code Signing Bypass iOS	3.002 WiFi RCE+LPE iOS/Android	3.003 SS7					6.001 LPE to Kernel iOS/Android	4.003 SBX for Chrome Android	4.004 SBX for Safari iOS
Up to $50,000	5.002 Code Signing Bypass Android	5.003 Secure Boot iOS	3.004 RCE via MitM iOS/Android			6.002 LPE to Root iOS/Android	4.005 Chrome RCE w/o SBX iOS/Android	4.006 Chrome UXSS/SOP iOS/Android	4.007 Safari UXSS/SOP iOS	4.008 Safari RCE w/o SBX iOS
Up to $25,000	5.004 TrustZone Android	5.005 Verified Boot Android			6.003 LPE to System Android	7.001 ASLR Bypass iOS/Android	7.002 kASLR Bypass iOS/Android	7.003 Seccomp Bypass Android	7.004 RKP Bypass Android	7.005 Knox Bypass Android
Up to $15,000	9.001 Information Disclosure iOS/Android							8.001 Passcode Bypass iOS	8.002 Touch ID Bypass iOS	8.003 PIN Bypass Android

BUG BOUNTY PROGRAMS

Apple's bug bounty program hindered by low payouts, report says

By Mikey Campbell
Thursday, July 06, 2017, 04:13 pm PT (07:13 pm ET)

Apple's invite-only bug bounty program is off to a slow start as security researchers in search of high payouts are saving discovered exploits for high-price sales on the gray market.

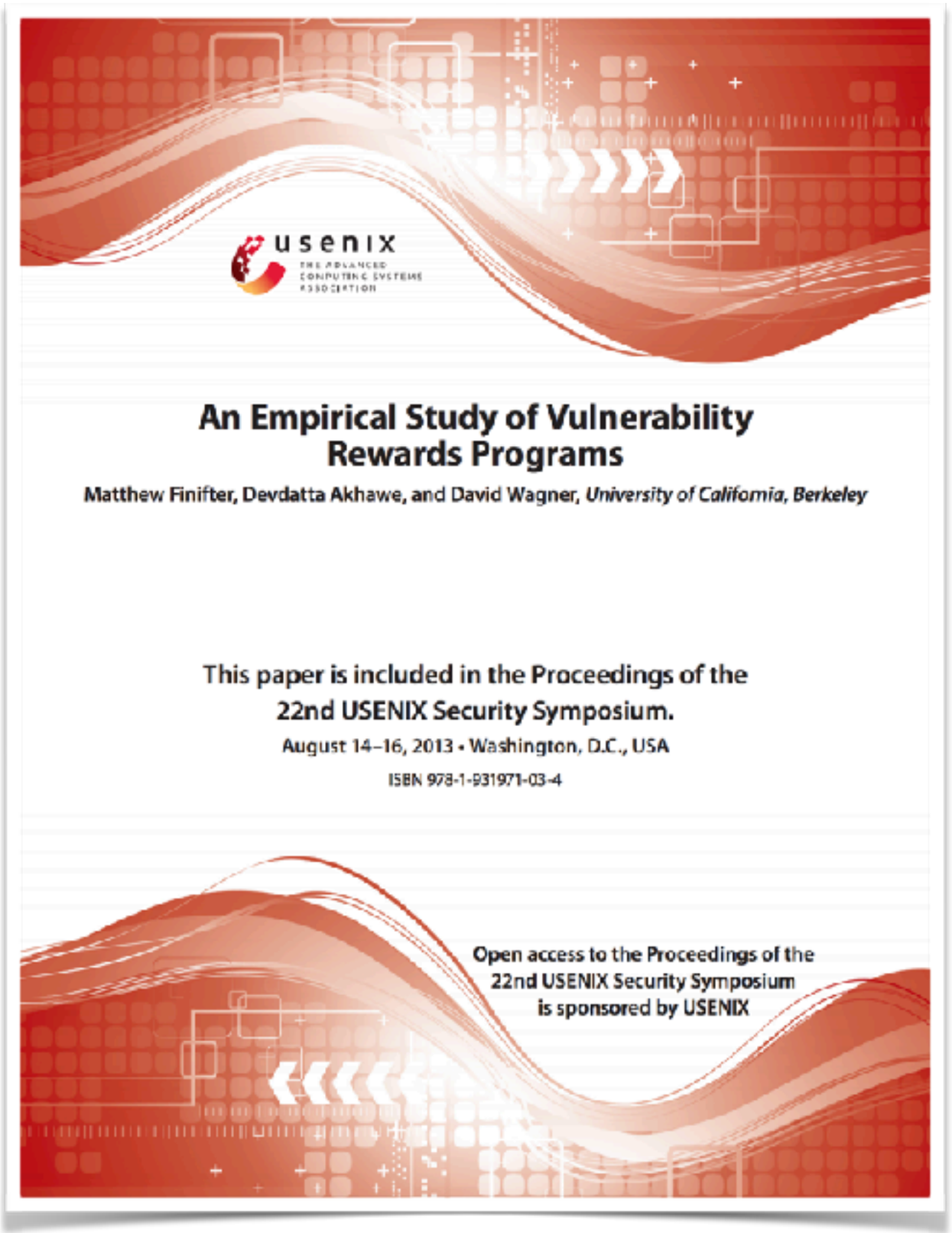


Apple's Ivan Krstic announces the bug bounty program at Black Hat USA 2016.

$200k < $1.5M

iOS bugs are too valuable to report

BUG BOUNTY PROGRAMS



Studied Chrome & Firefox VRPs

VRPs yield patched vulnerabilities

28% of Chrome's patches

24% of Firefox's patches

VRPs are a good deal (for vendors)

Nowhere near full-time salary

What about today's bug bounty programs? What about 3rd parties?

SPAM

- Unsolicited, annoying email (or posts on blogs, social networks, etc.) that seeks to
  - Sell products
  - Get users to install malicious software

- Typical defenses
  - Look for key words in the messages
  - Block certain senders (**SpamHaus** blacklist of IP addrs)

- But what is the economics behind it all?
  - How do they send out so much email?
  - Are they selling real things? How?

SENDING SPAM

- Tons of email to send, and easy to block a single IP address from sending
- Need lots of IP addresses
  - But since SMTP (email) uses TCP, we need to actually be able to operate those IP addresses
- Buy lots of computers? (expensive)

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Compromise lots of computers!

BOTNETS

- Collection of compromised machines (bots) under unified control of an attacker (botmaster)

- Method of compromise decoupled from method of control
  - Launch a worm/virus, etc.: remember, payload is orthogonal!

- Upon infection, a new bot "phones home" to *rendezvous* with botnet **"command-and-control" (C&C)**

- Botmaster uses C&C to push out commands and updates

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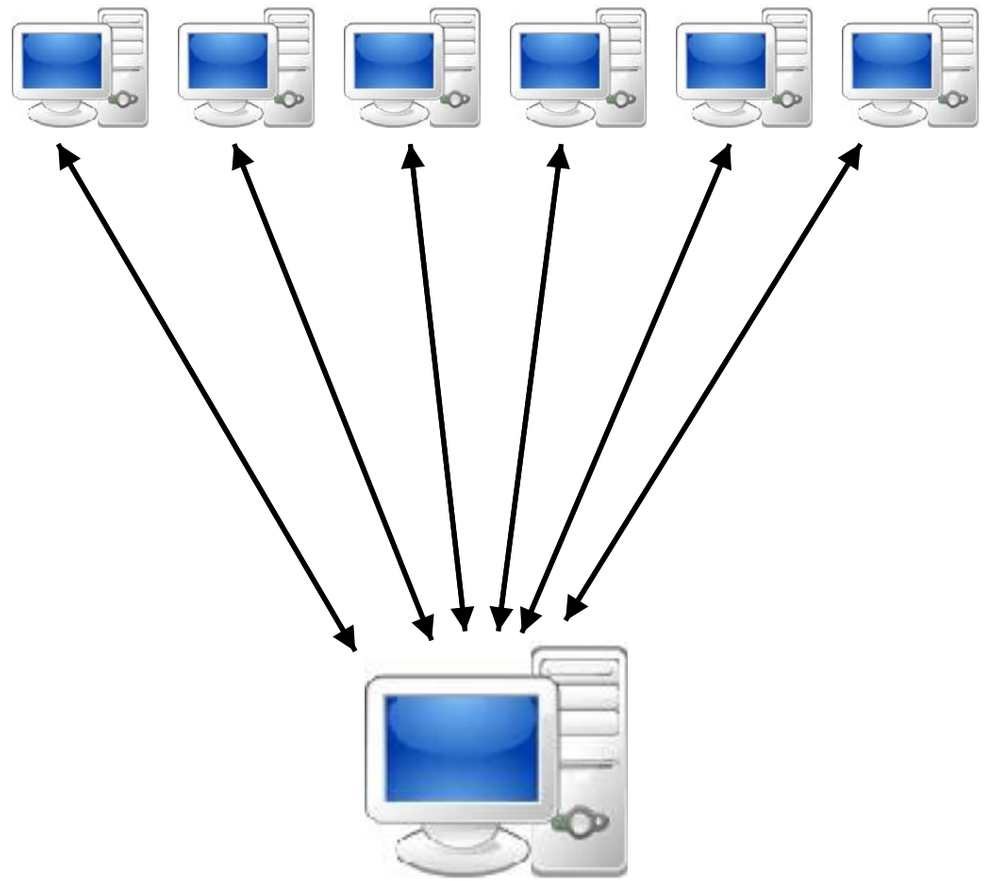

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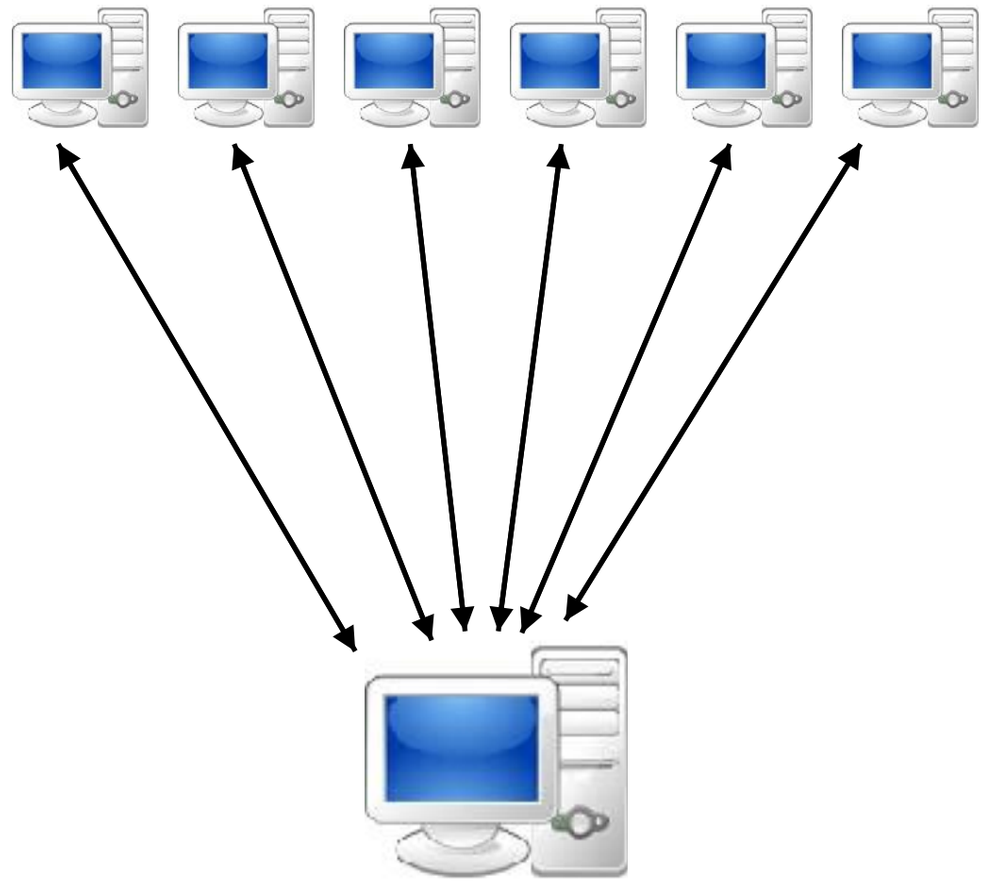


C&C

Topology can be star (like this), hierarchical, peer-to-peer…

SUPPORTING CLICKS

- Ideally a user will click on an embedded URL

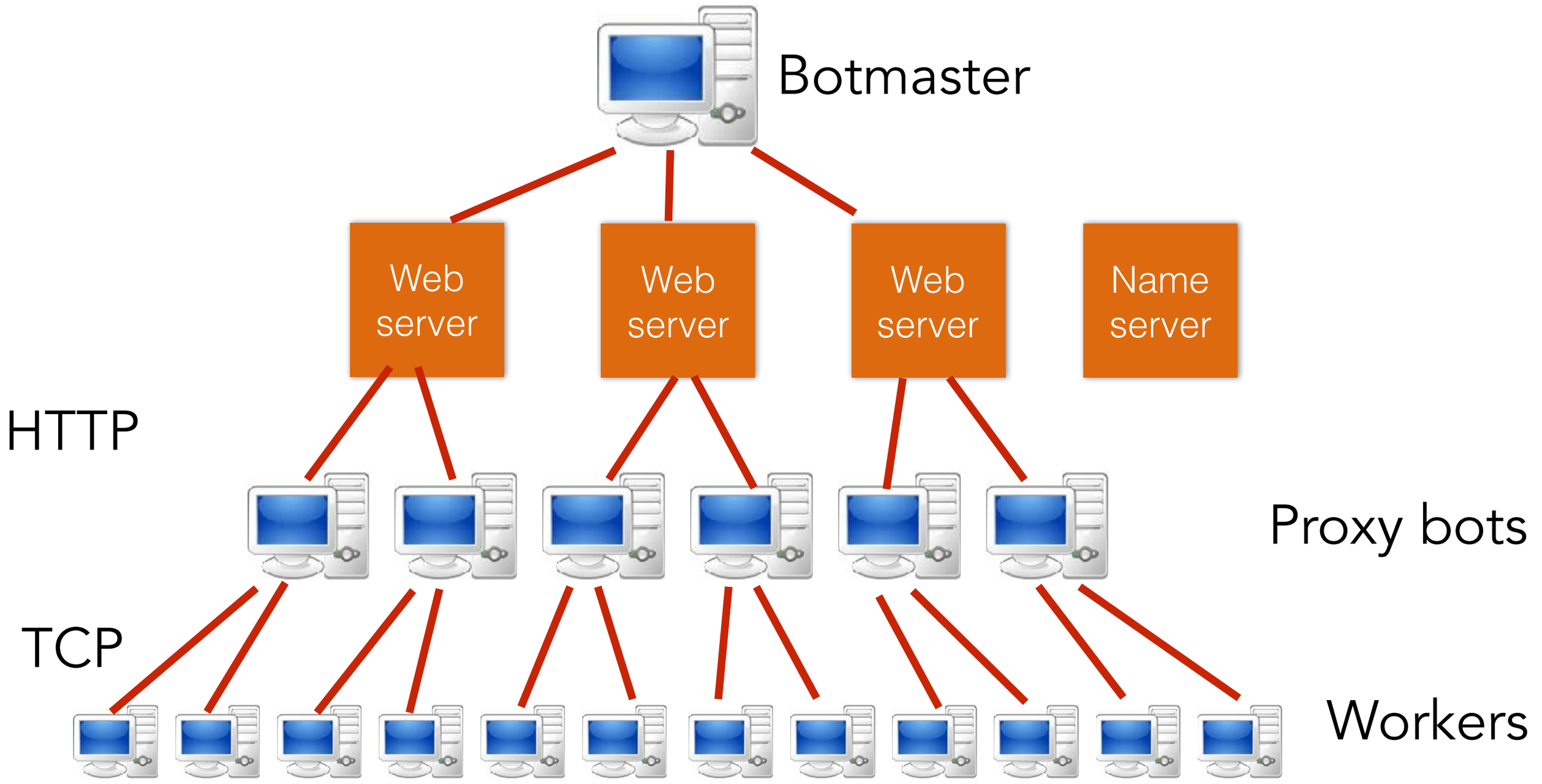
- Result is more complex than just going to a web server
  - Defensive measures: URL and domain **blacklisting** & **takedown notices** by ISPs

- Confuse defenses (esp. blacklisting) with moving targets:
  - **Redirection sites** (legit-looking URL, like a URL shortener, or just manage DNS yourself and create throwaway domains that redirect to a more permanent domain)
  - **Bulk domains**: purchased from a reseller or as part of an affiliate program (more later)

- But web servers are static, so how do we keep them from being shut down due to blacklisting and takedown notices?

SPAMBOT

Botnet used for sending spam



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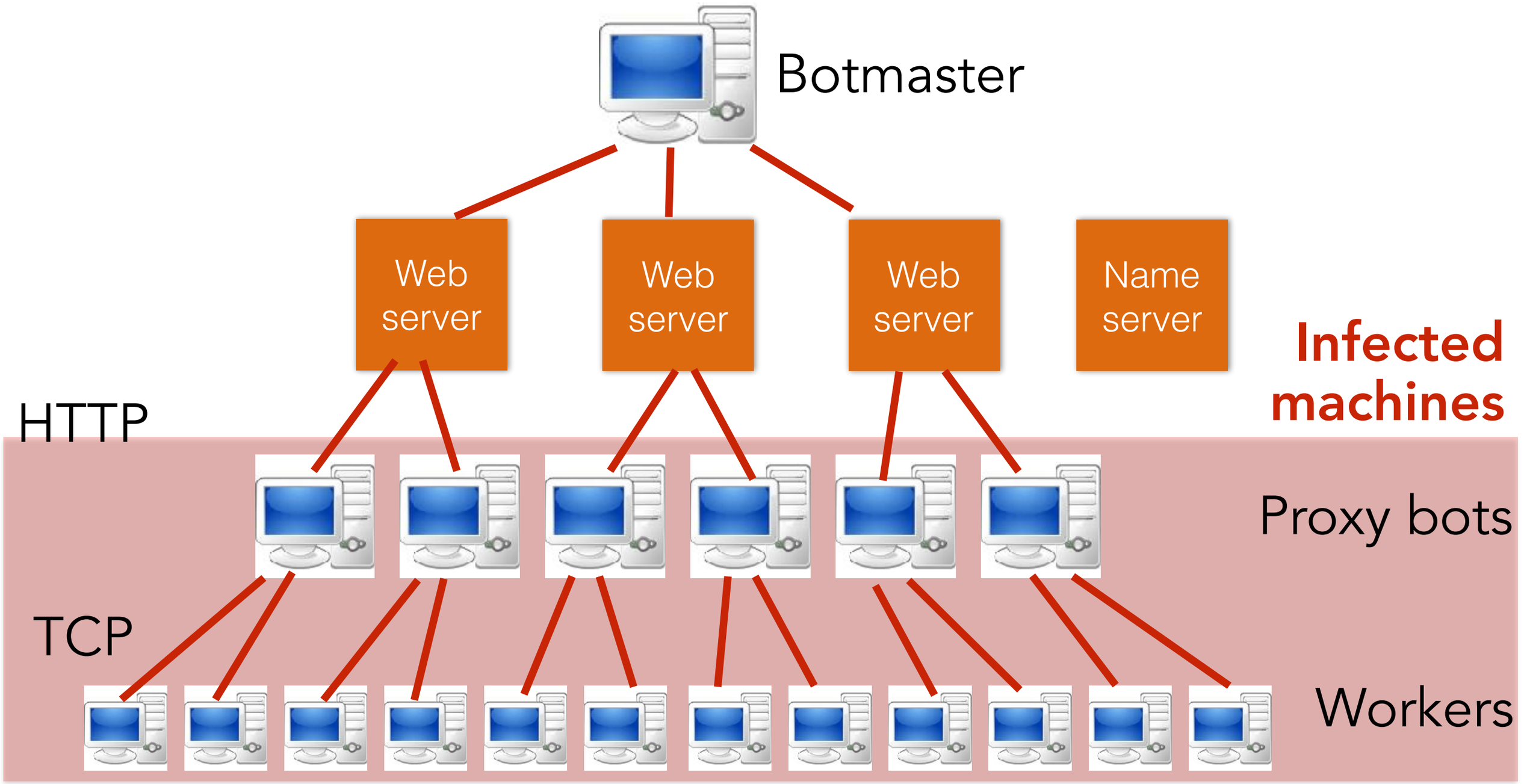

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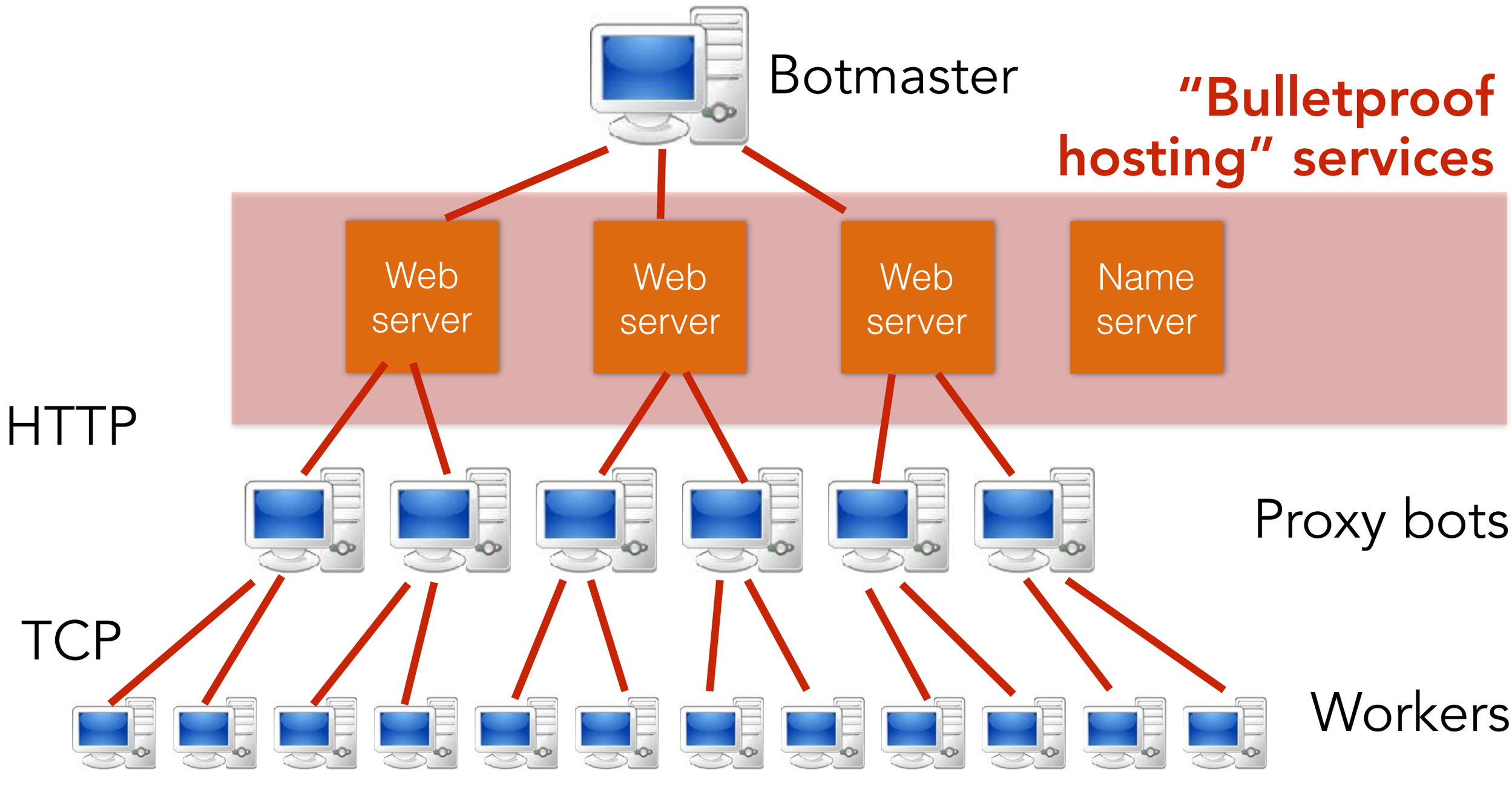

BULLETPROOF HOSTING SERVICES

- Services / specific hosts are often blocked by appealing to their ISPs (“please block this user..”)

- Bulletproof hosting services will refuse to block you (for a price)

- Many have been taken down
  - Often linked to criminal organizations

- Storm botnet: Controller likely run by Russian Business Network
  - Used Atrivo as their bulletproof hosting service

WHY SO MANY LEVELS OF INDIRECTION?

- Many workers send email
- User clicks: gets sent to a proxy bot, who redirects to a web server
- Why proxies?
  - To subvert defenses that block IP addresses
  - Keep the IP address for a given host (buydrugs.ru) moving
- **"Fast flux"** network
  - Short-lived TTLs in DNS responses (hostname to IP address mapping changes quickly)
  - Web proxies to a set of fixed web servers

AN ASIDE ABOUT BOTNETS

MONETIZING BOTNETS

- General malware monetization approaches apply:
  - Keyloggers (steal financial, email, social network, etc. accounts)
  - Ransomware
  - Transaction generators
    - Watch user's surfing
    - Wait to log into banking site and inject extra money, then alter web server replies to mask change in user balance
    - Or wait until the user clicks and inject your own, too.

MONETIZING BOTNETS

- Additionally, botnets give you massive scale
  - DDoS
  - Click fraud
  - Scam infrastructure
    - Hosting web pages (e.g., for phishing)
    - Redirection to evade blacklisting/takedown notices
- Spam

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None of these cause serious pain for the infected user!

Users have little incentive to prevent these

ADVERTISING YOUR BOTNET

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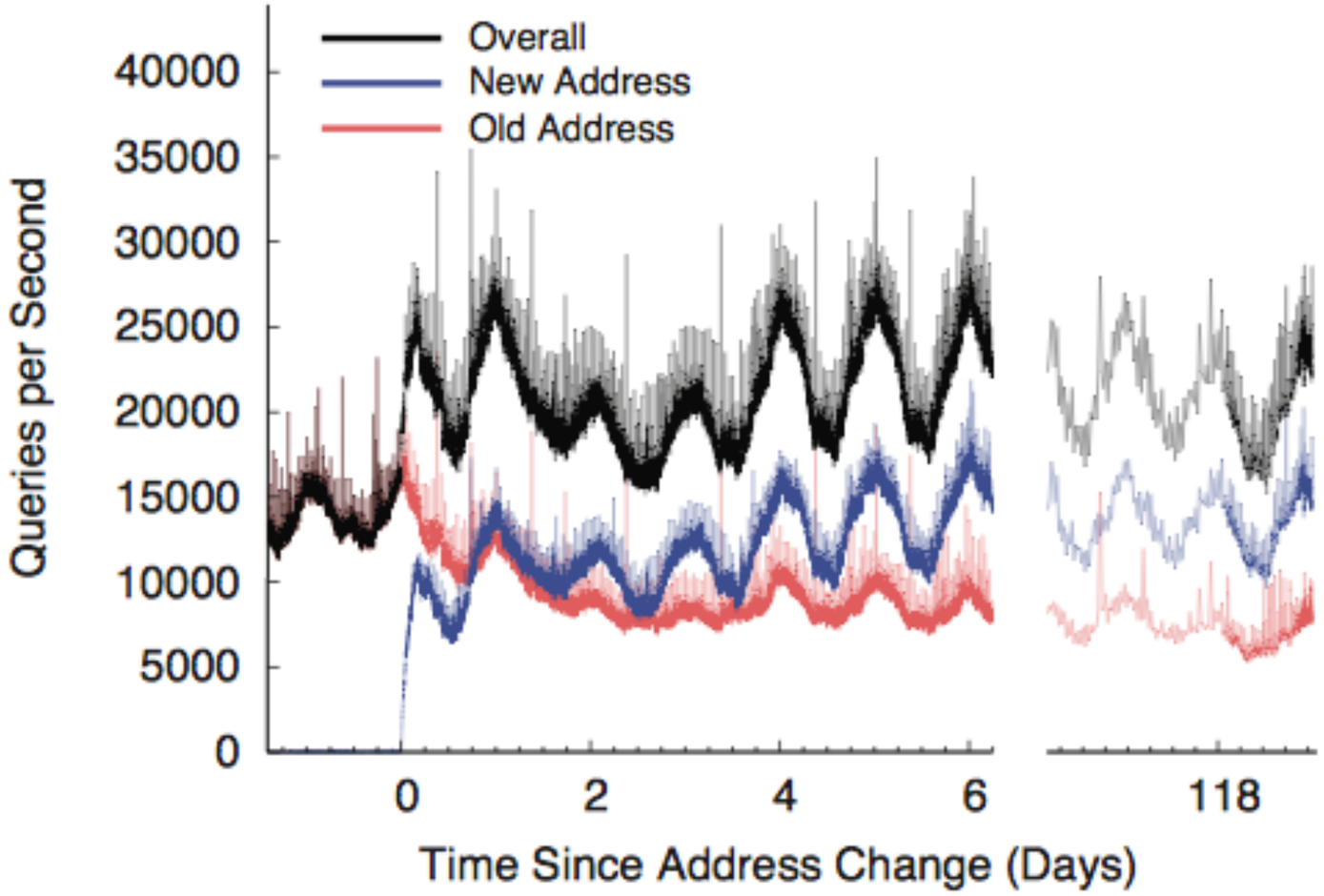

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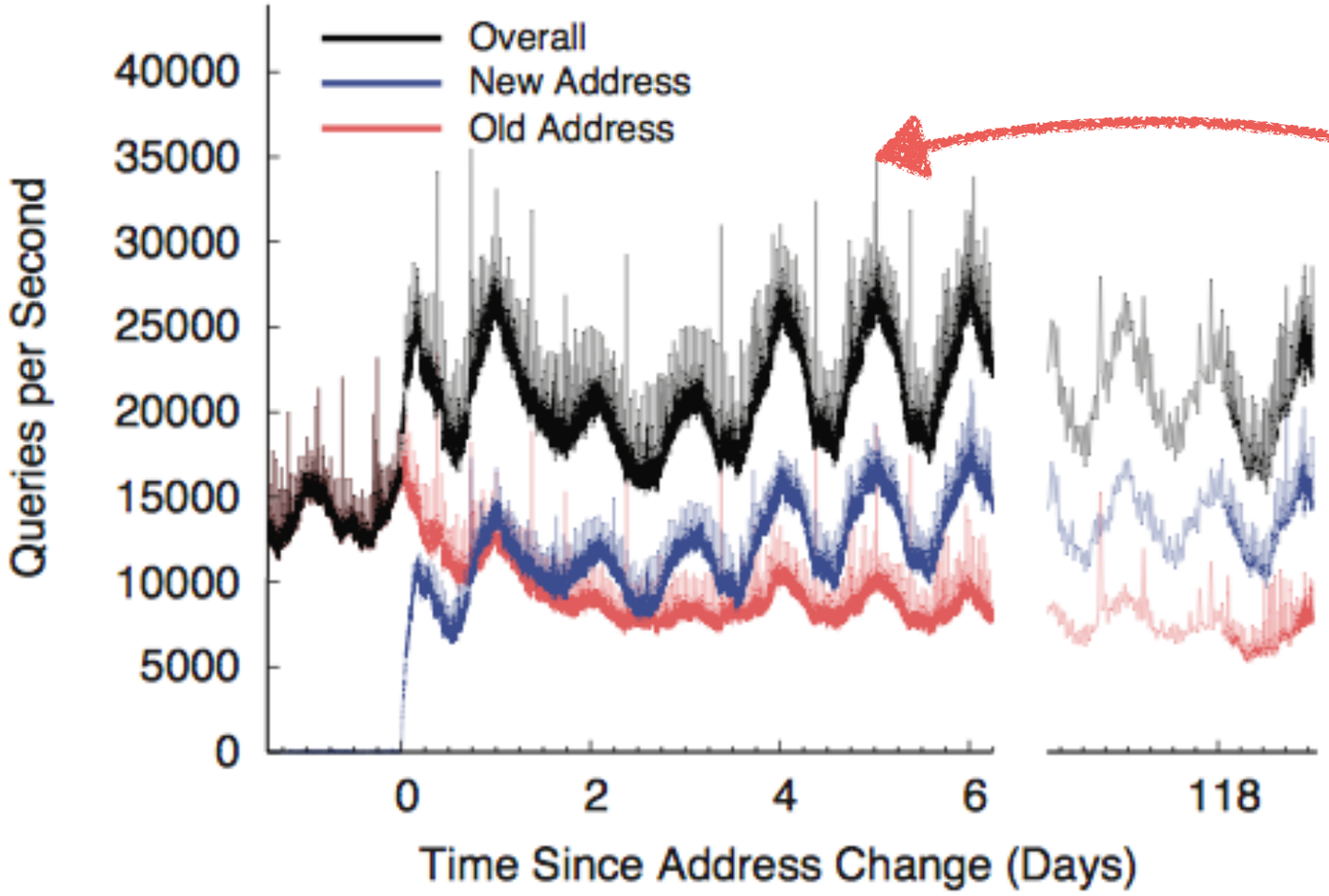

"Look for the surge
4 days from now"

THE IMPORTANCE OF BOTNETS

- Botnets represent the “great modern threat” of the Internet

- Why not worms?

THE IMPORTANCE OF BOTNETS

- Botnets represent the “great modern threat” of the Internet

- Why not worms?
  - Greater control over botnets
  - Less emergent
  - Quieter
  - Flexible

TAKING DOWN BOTNETS

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- Approach #1: **prevent** the initial bot infection
  - Infection is decoupled from bot's participation in the botnet, so this is equivalent to preventing malware infections in general - *hard*

- Approach #2: **Take down** the C&C master server

- Botmaster counter-measures?

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  - Try a random subset looking for C&C server.
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Counter-counter measure?

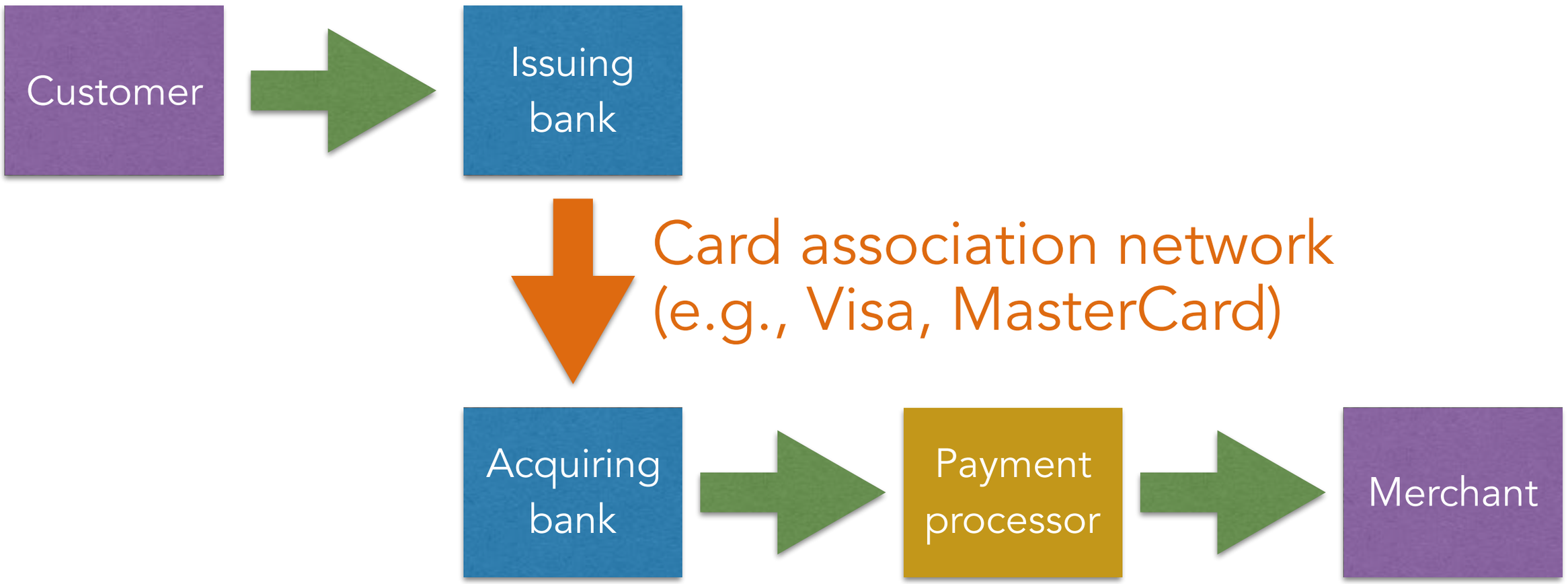
BACK TO SPAM

AFFILIATE PROGRAMS

Markets drive efficiency and specialization:
some specialize in botnets, others in spam

- You can join an affiliate program!
  - You send out emails and get a commission (30–50%)
- Affiliate program provides:
  - Storefront templates, shopping cart management
  - Analytics support
  - Advertising materials
  - Central web service interface for affiliates to track conversions and to register for payouts
  - Domains bought in bulk
  - …

GETTING PAID



Facilitates payment

SHIPPING GOODS

- Business-to-business websites will make connections across many different goods
  - Alibaba, EC-Plaza, ECTrade, …
- Commonly offer “drop shipping”
  - The spambot operator does not need to purchase any warehouse/storage

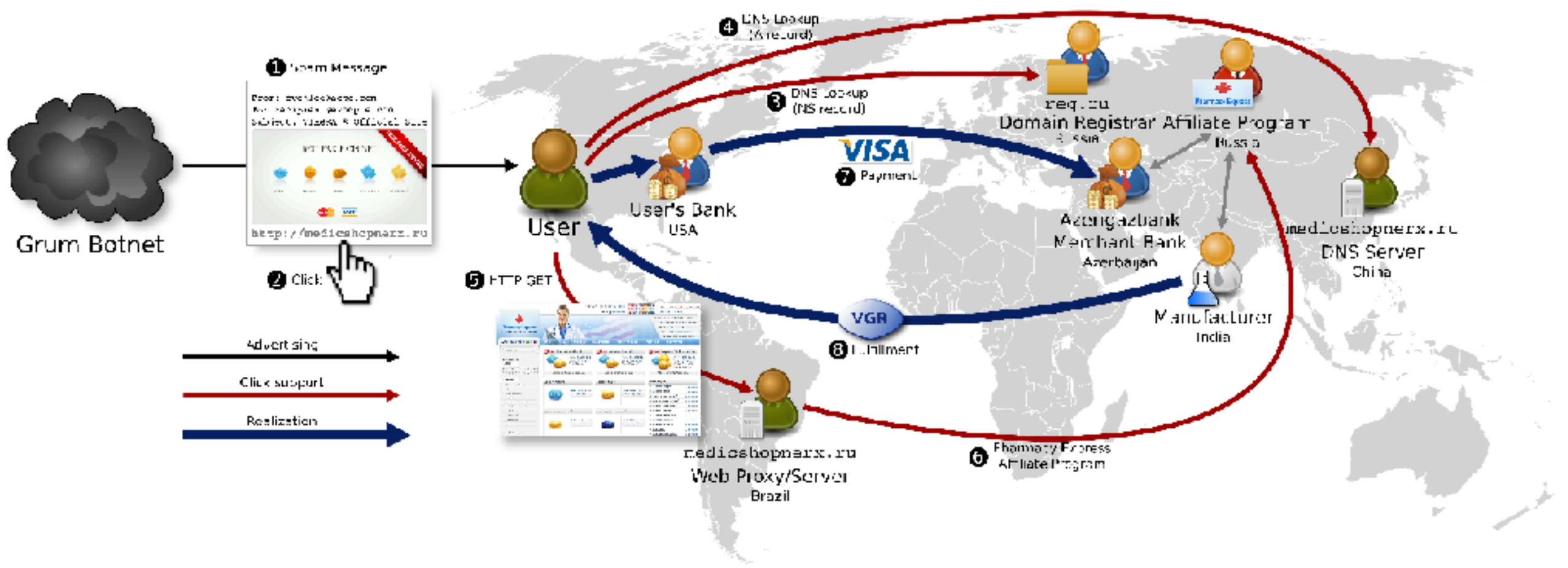
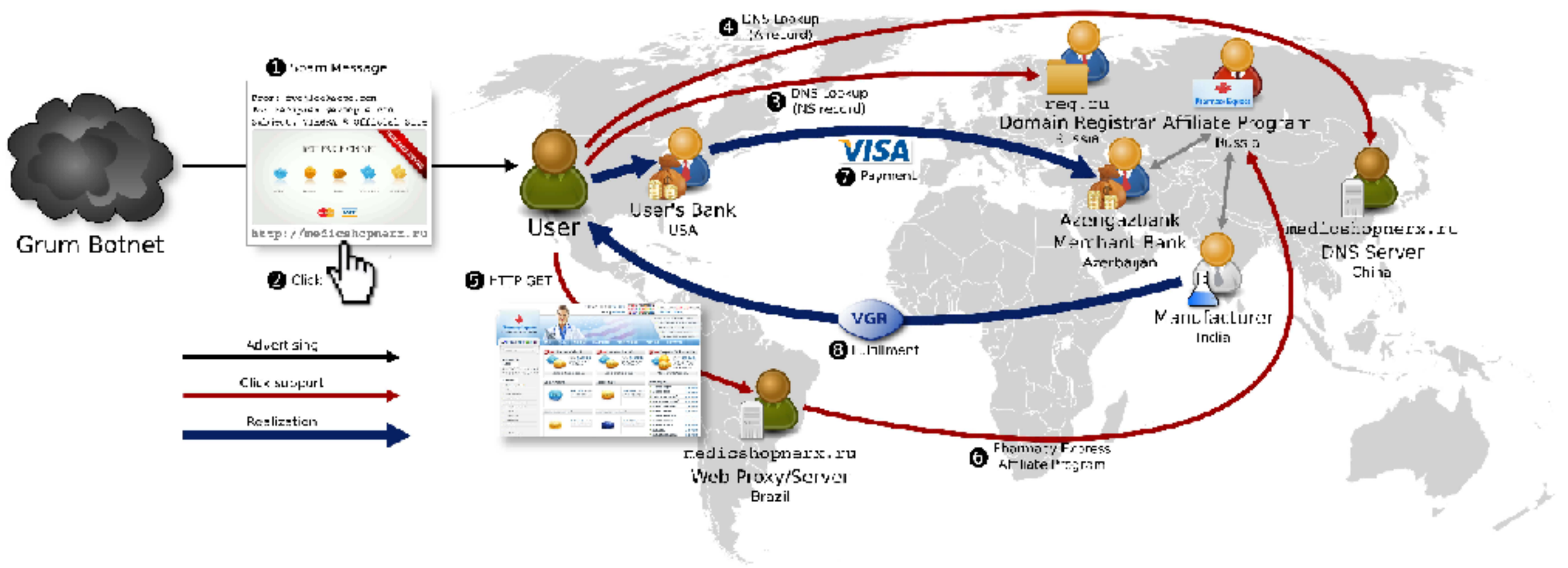


Figure 1: Infrastructure involved in a single URL's value chain, including advertisement, click support and realization steps.



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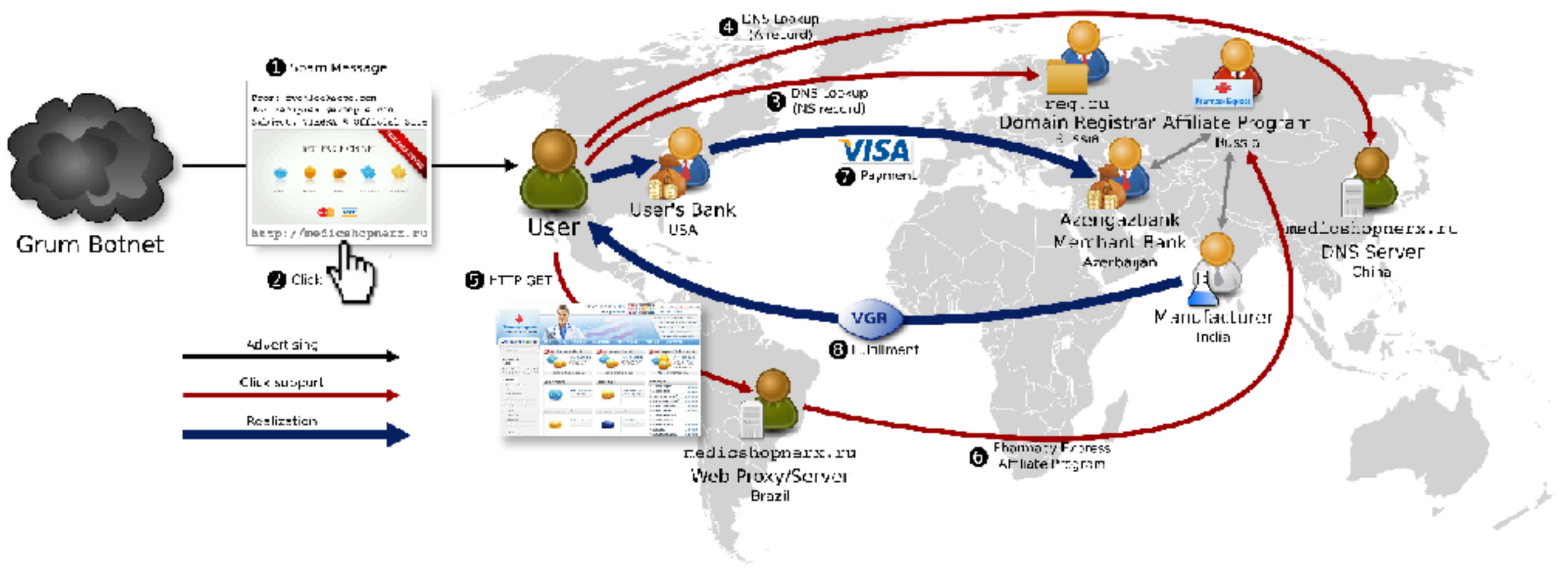

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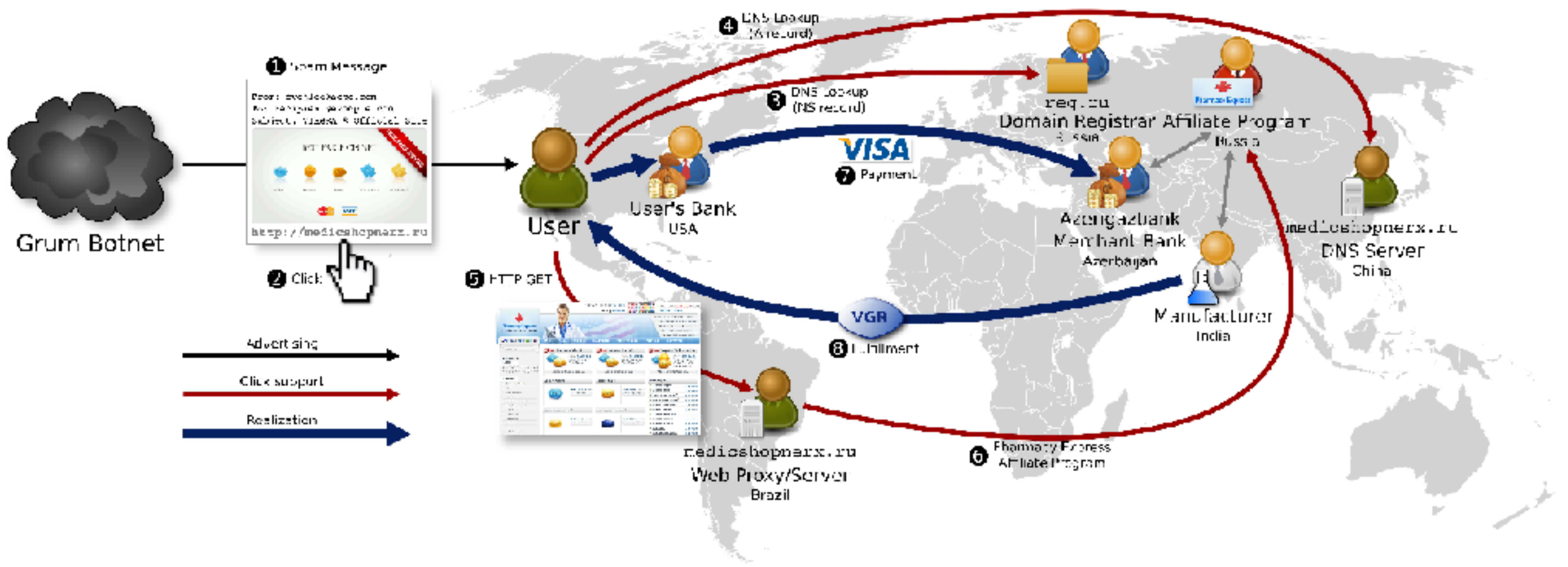
1. Spam delivered
2. User clicks



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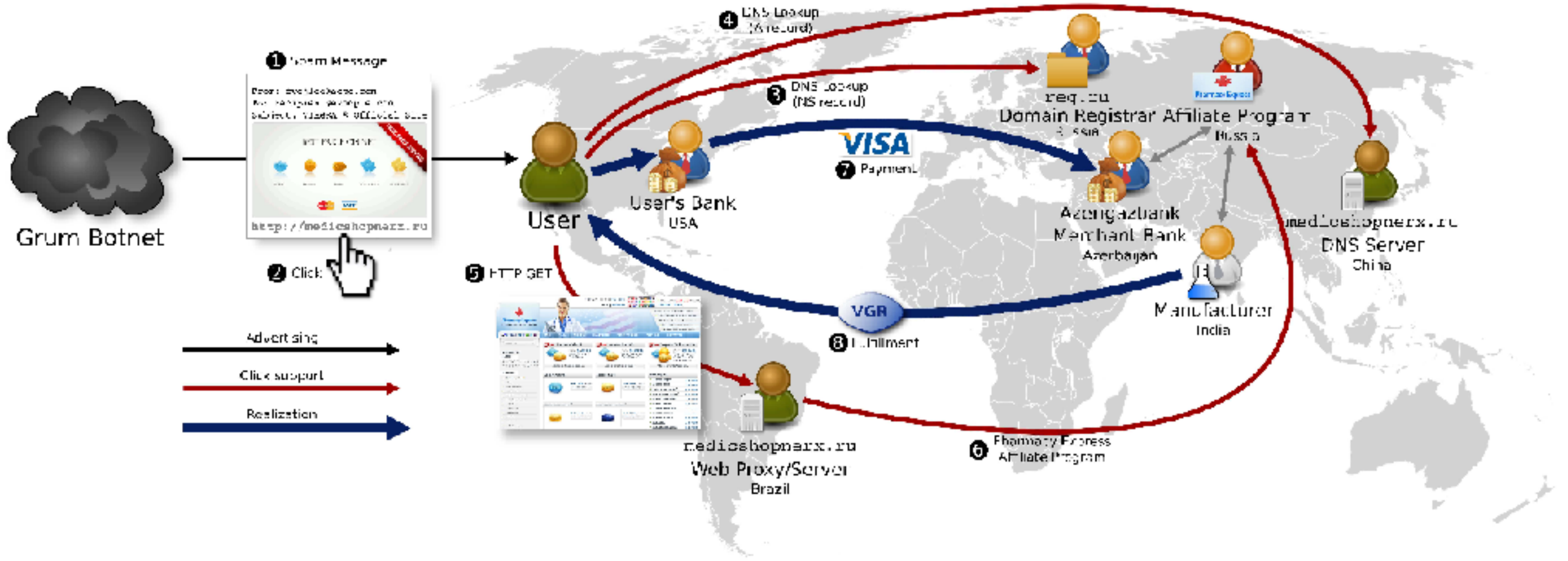
1. Spam delivered
2. User clicks
3. Domain registered by reg.ru



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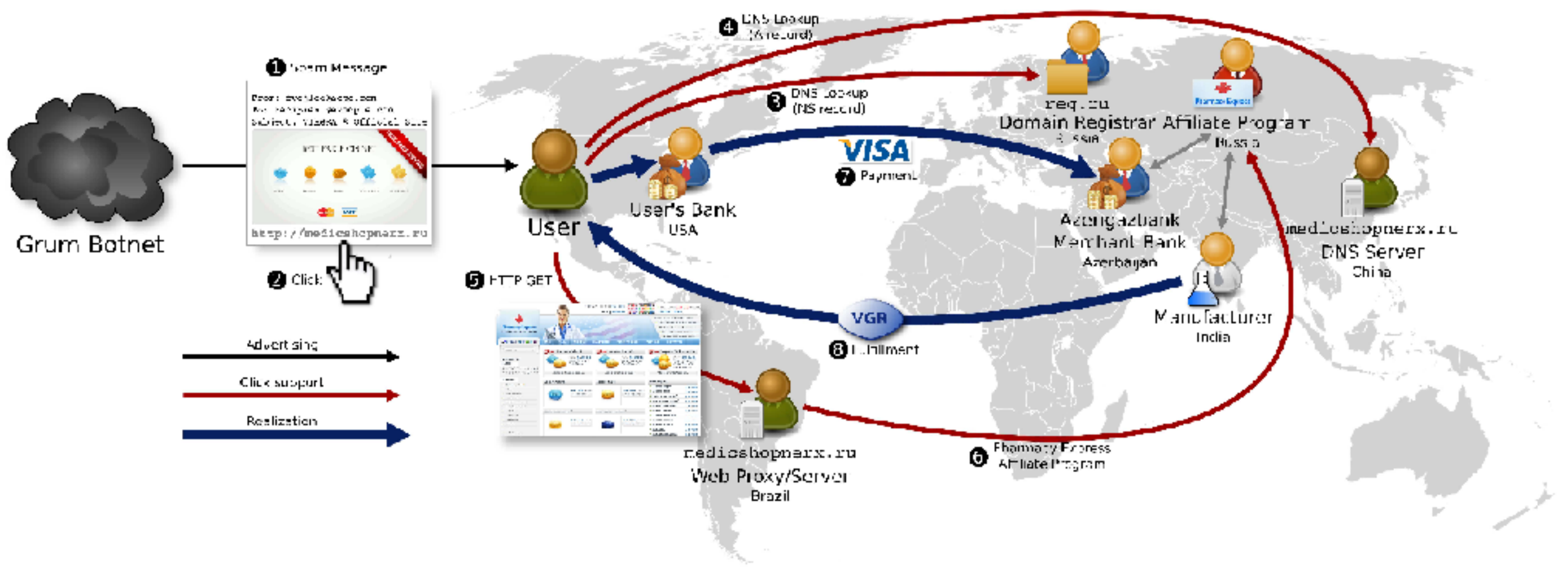

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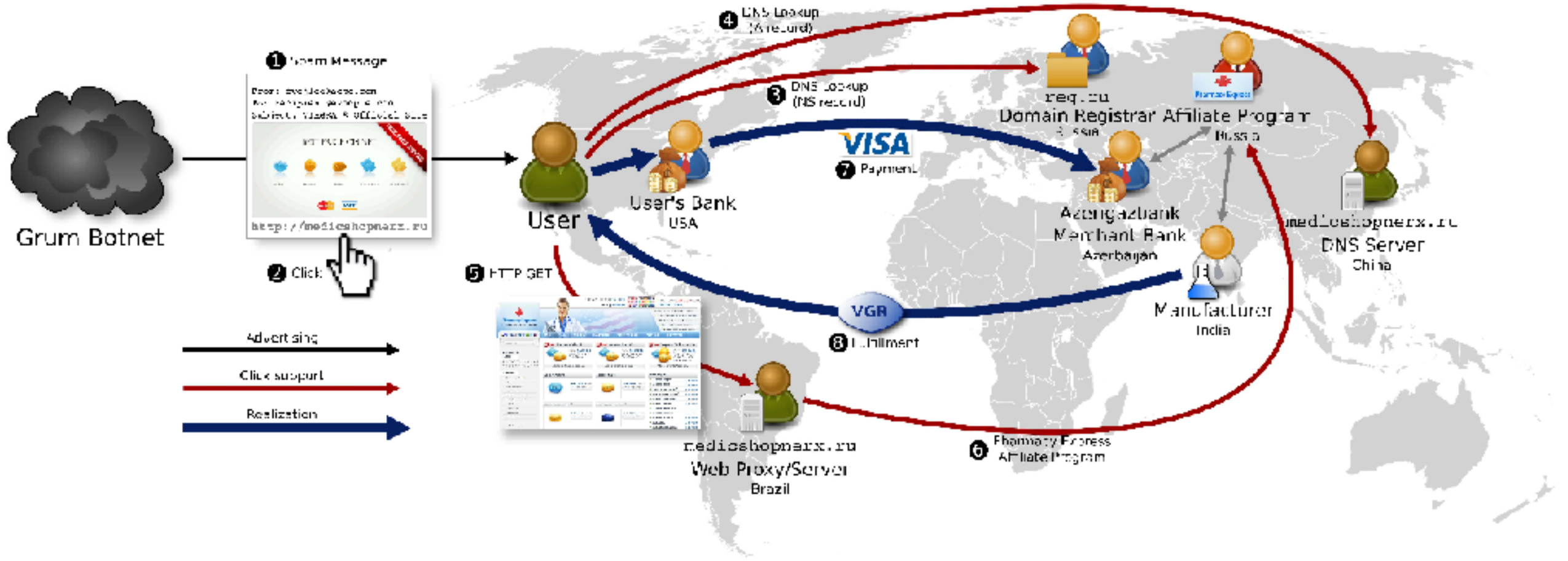

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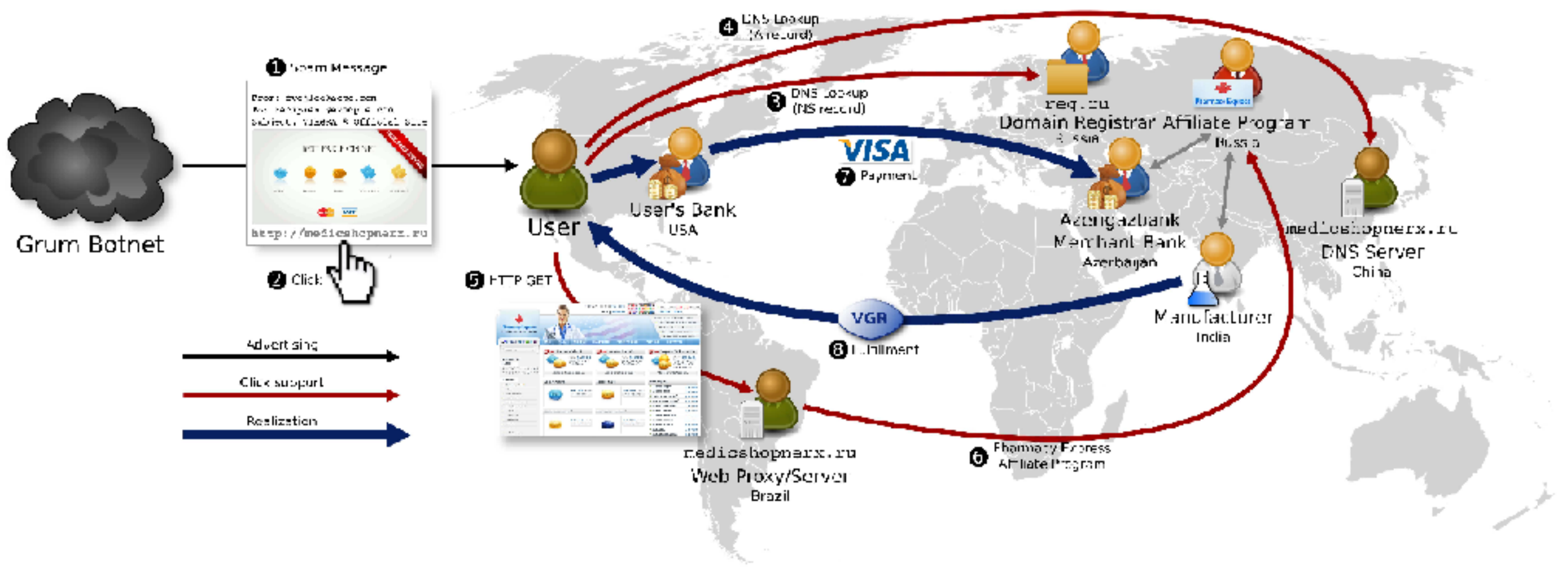

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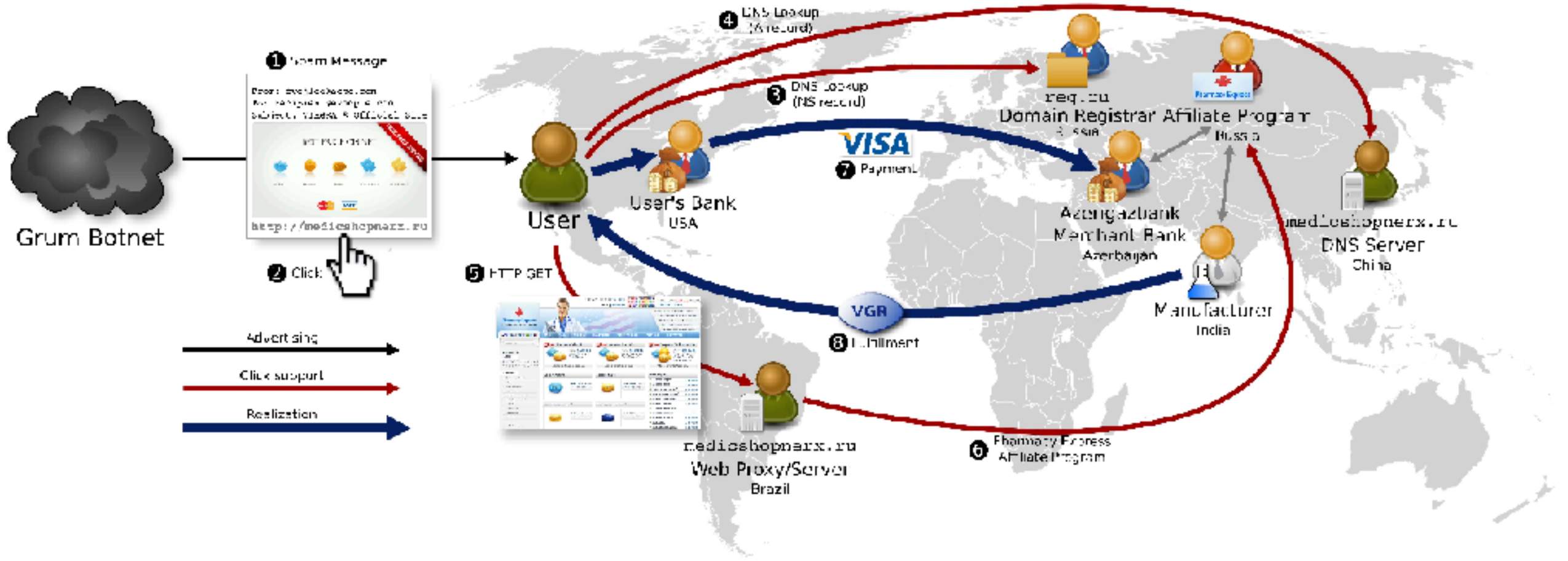

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8. Supplier in Chennai, India delivers 10 days later

ANALYZING SPAM CLICK TRAJECTORIES

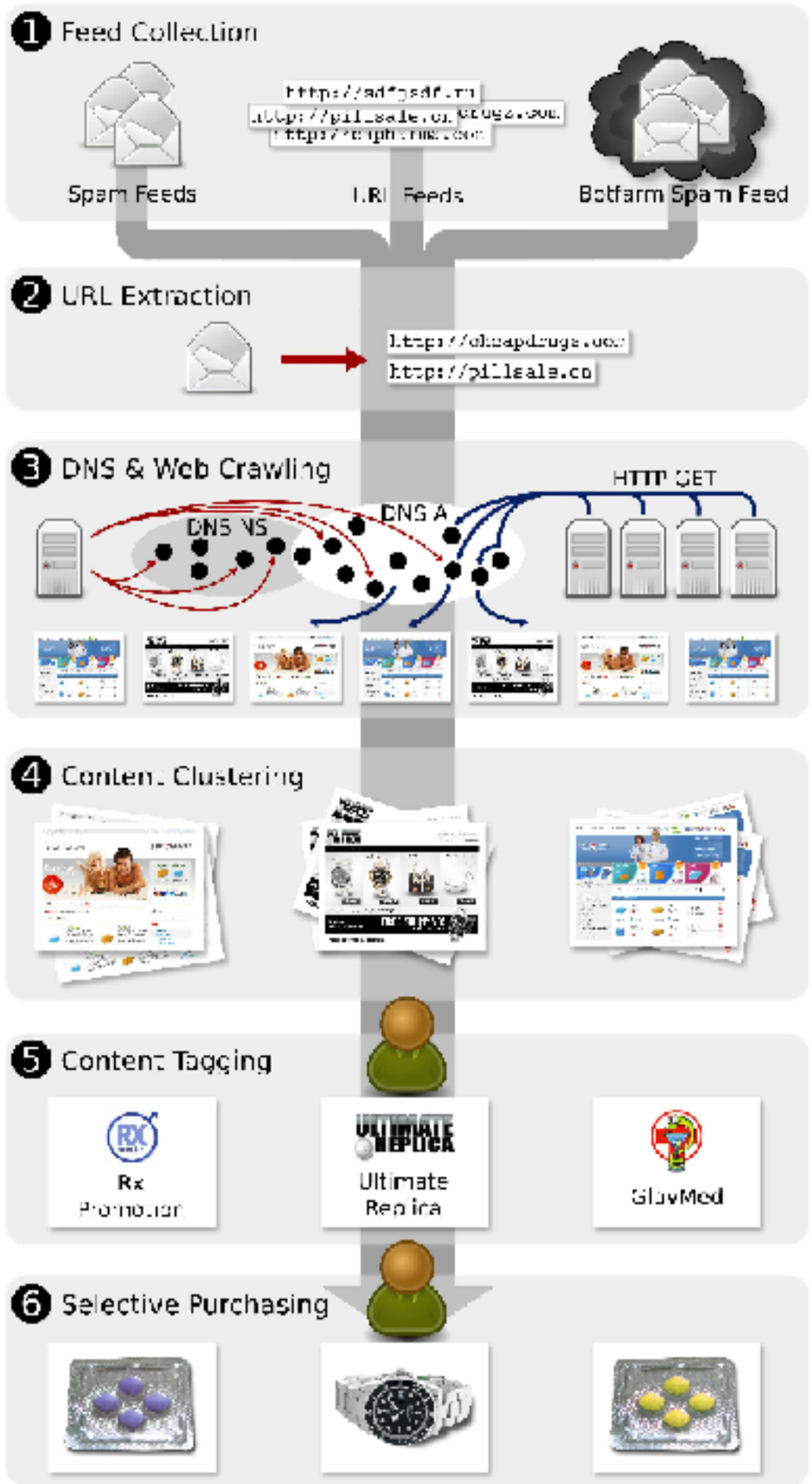

Figure 2: Our data collection and processing workflow.

Dataset

156 orders over 2 months

PURCHASE PAIRS

- Most *affiliate programs* provide a confirmation page with an order number

- This order number usually just increments

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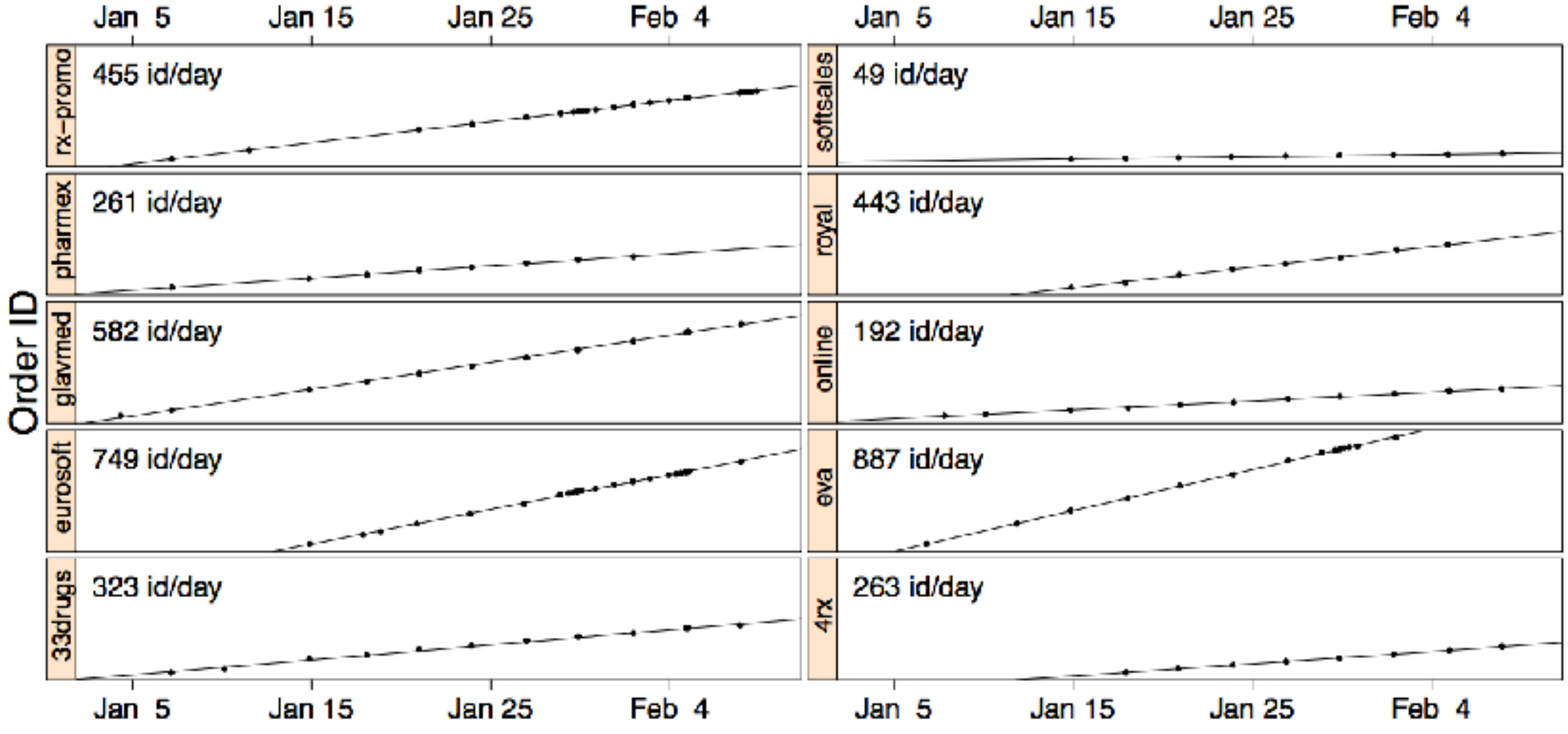

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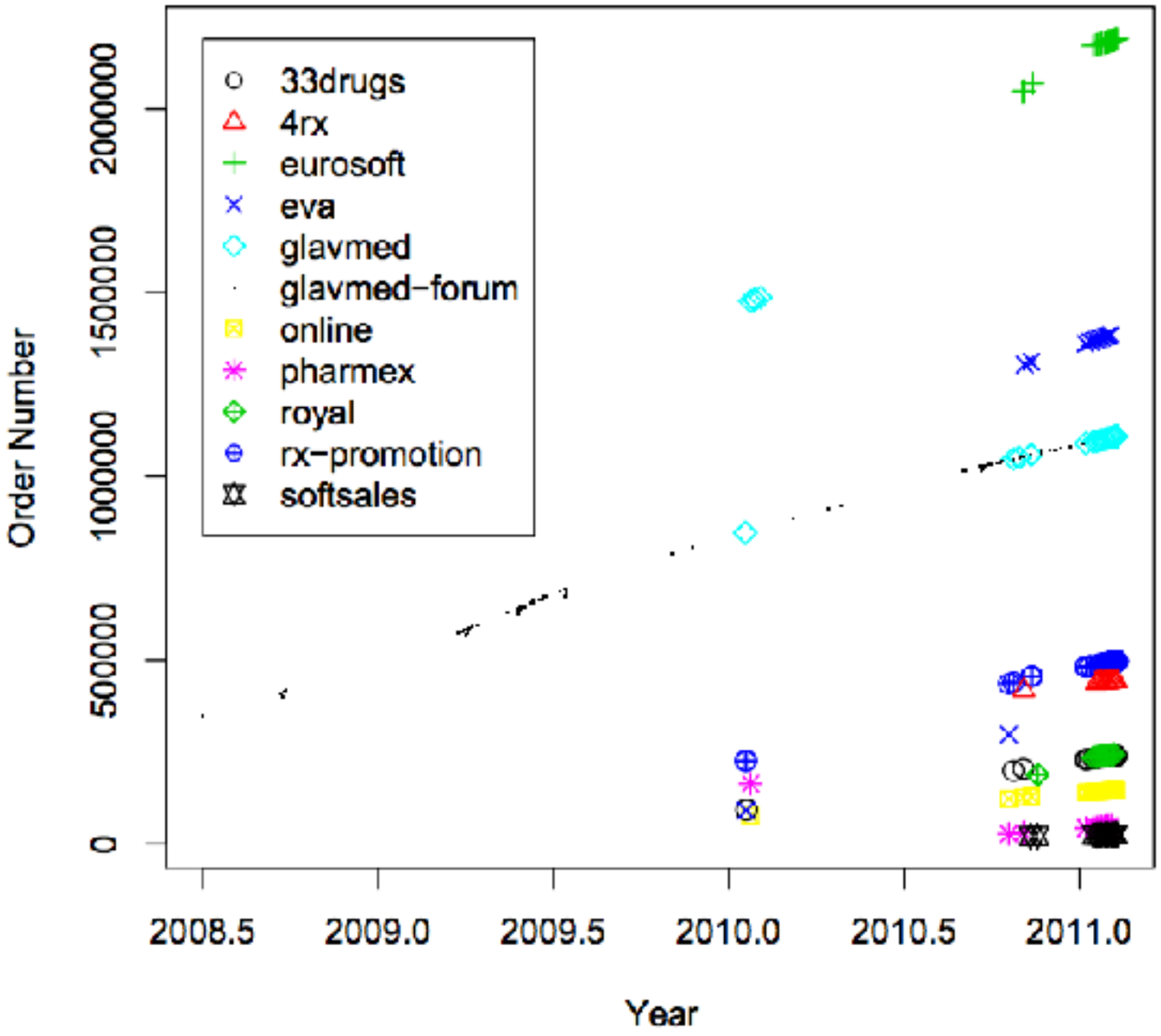


Figure 2: Order numbers (y-axis) associated with each affiliate program versus the time of attempted purchase (x-axis).

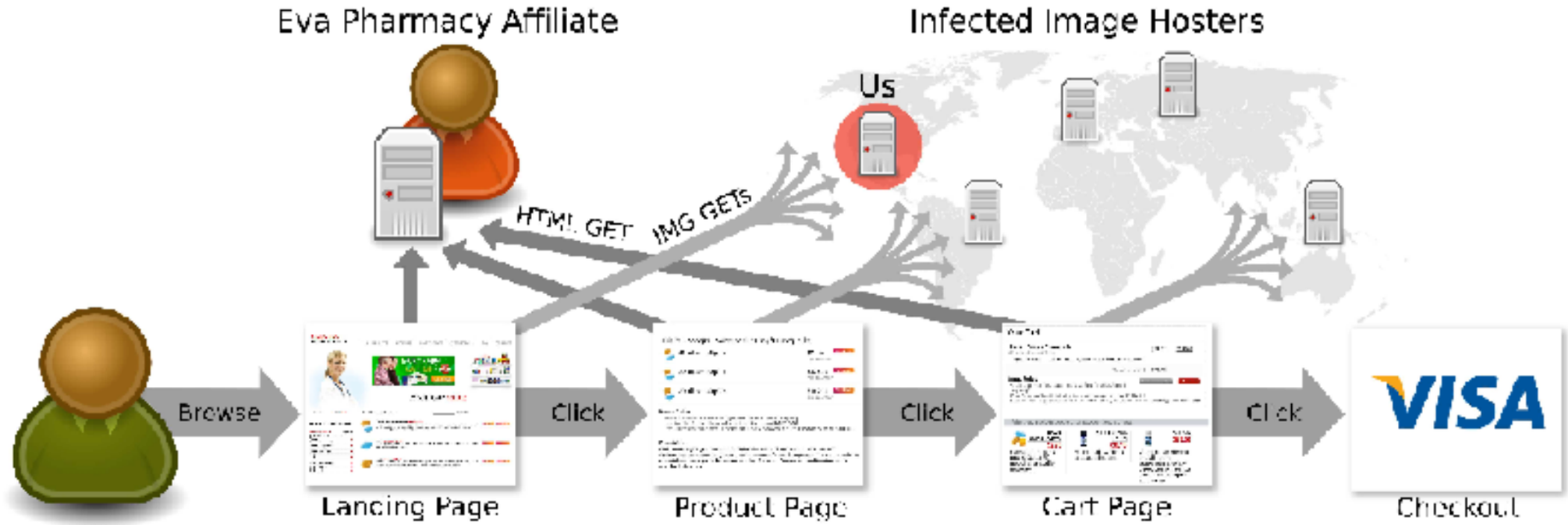
INFERRING WHAT PEOPLE BUY

- EvaPharmacy (a top 5 spam-advertised pharmacy affiliate program):
  - 2/3 of outsourced image hosting was to compromised 3rd party servers

- They contacted the owners of these servers and asked for logs

- Correlated image logs with purchases

METHODOLOGICAL SHORTCOMINGS



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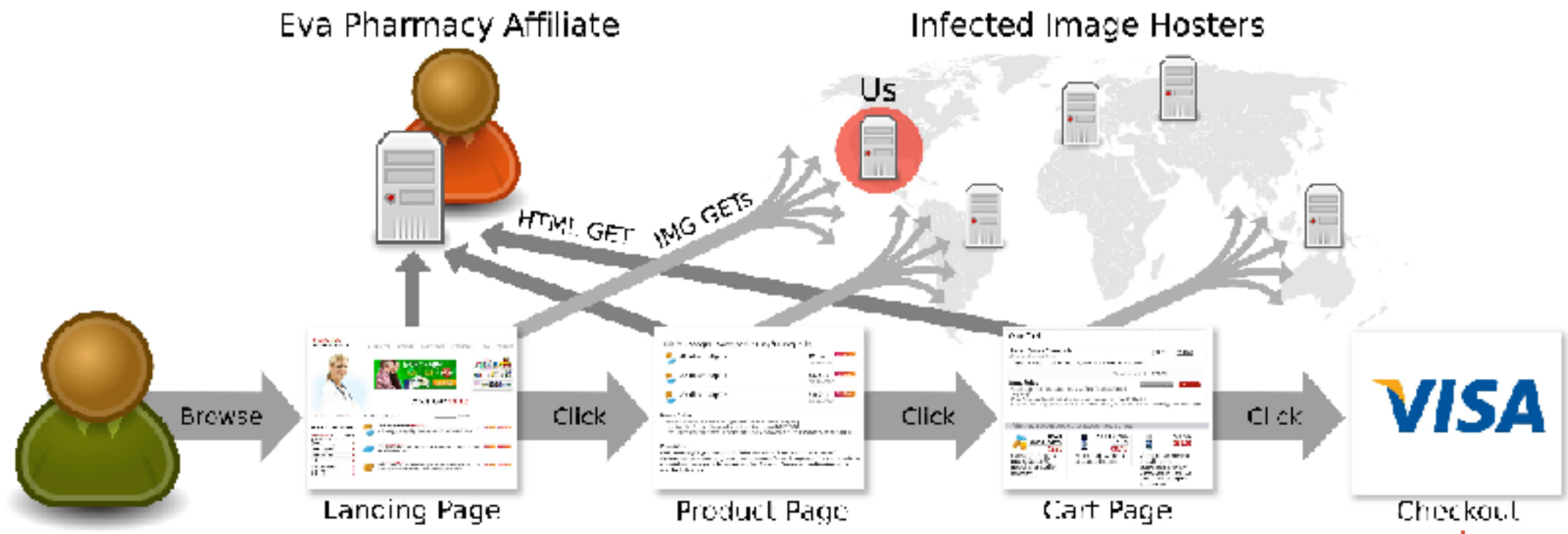

1. Checkout page does not include unique images

(can only infer it was in cart)

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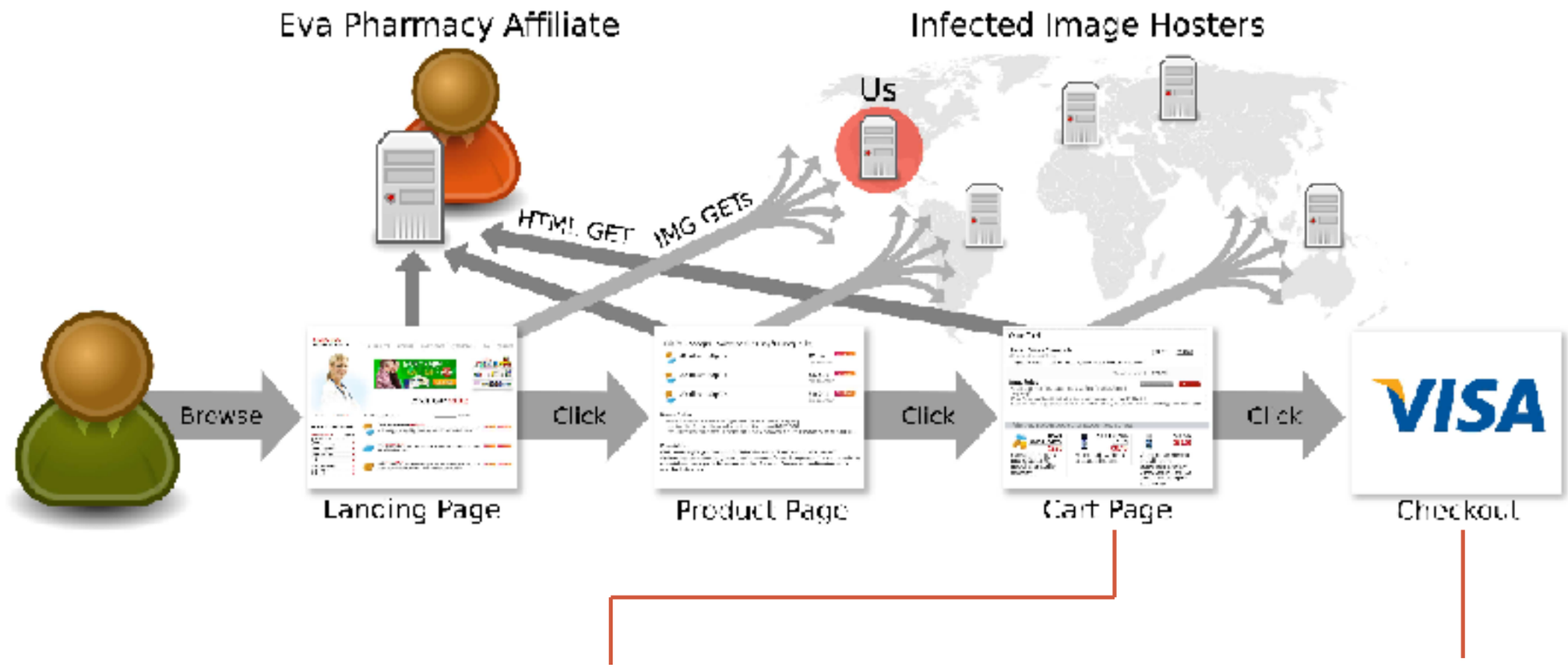

2. Images often independent of dosage/count

(cannot infer exact amount)

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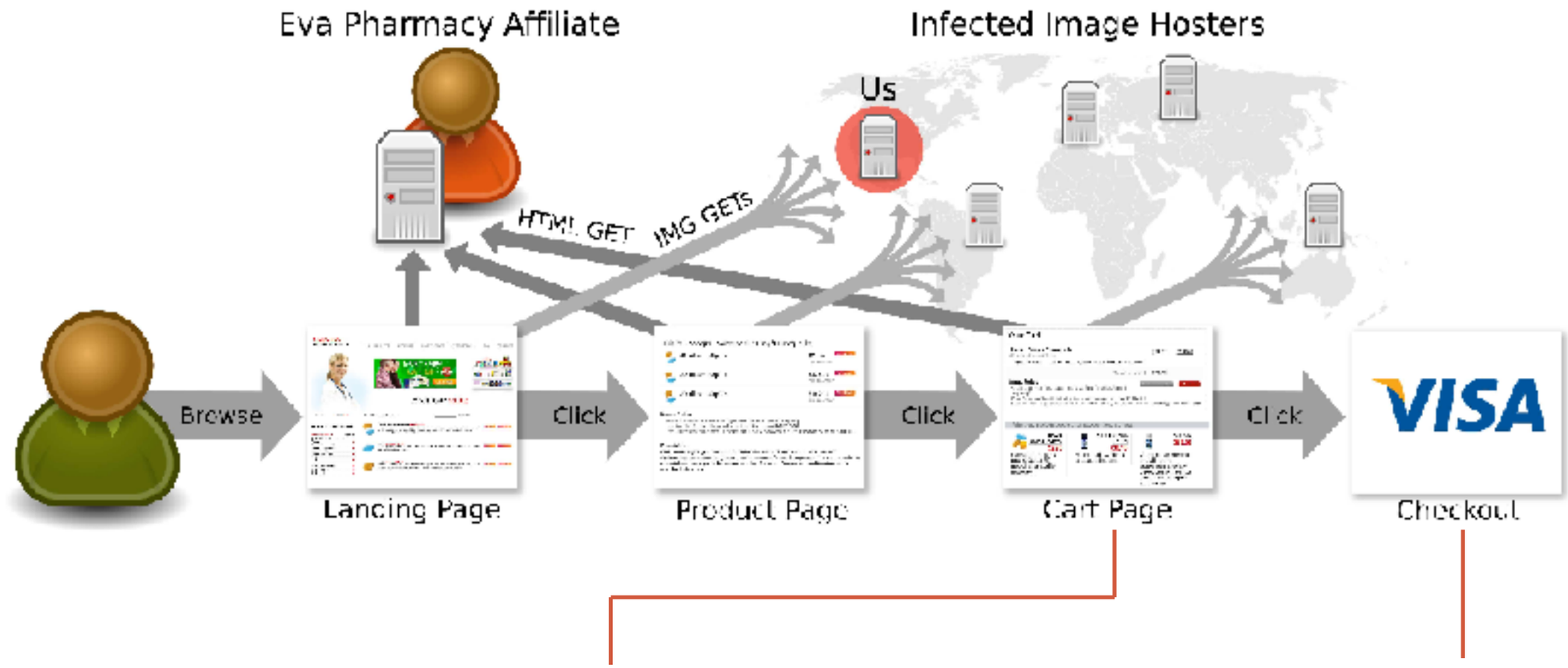

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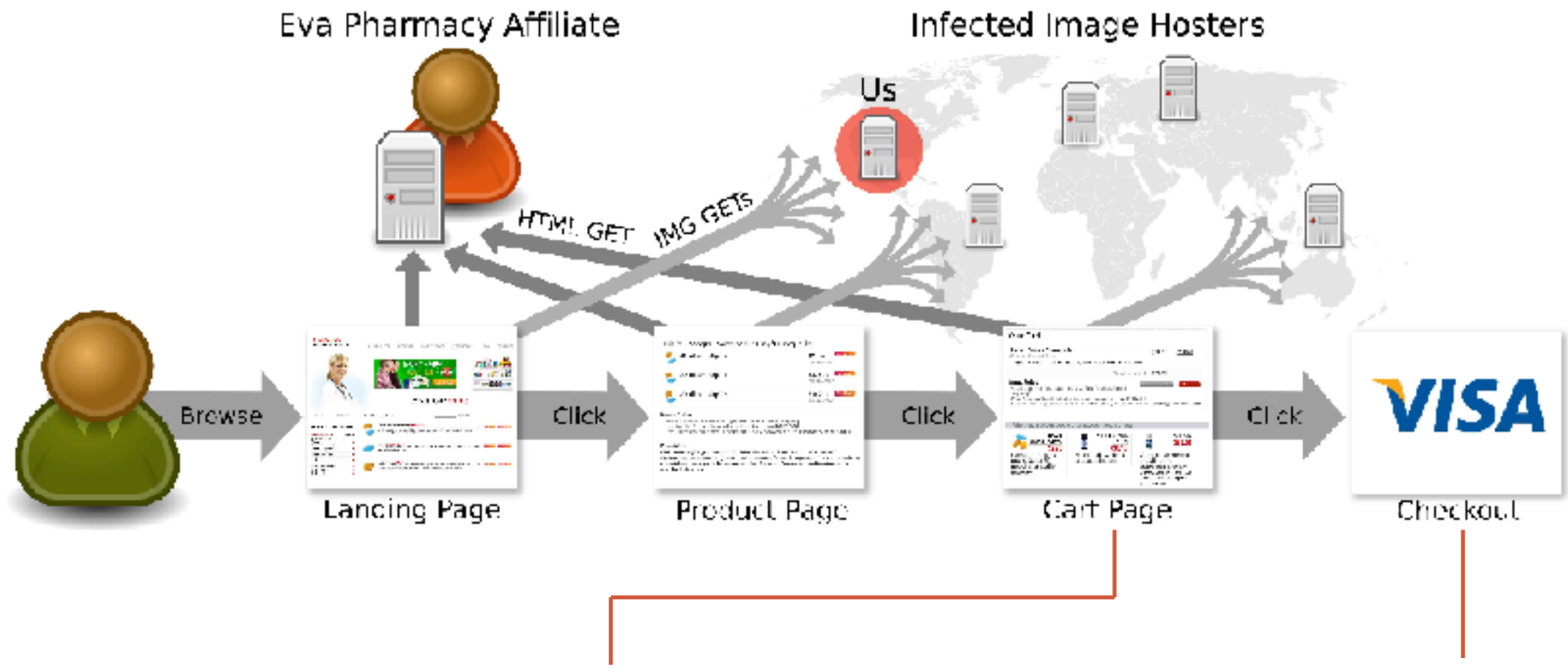

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3. Not all affiliates sell the same formularies

(EvaPharmacy study limited)

4. Almost all visitors from spam email

(potential bias in behavior?)

WHO/WHAT GETS SOLD

- Three most common products sold:
  - Pharmaceuticals (vast majority)
  - Replica luxury goods
  - Counterfeit software

- Run by relatively few affiliate programs

Stage	*Pharmacy*	*Software*	*Replicas*	*Total*
URLs	346,993,046	3,071,828	15,330,404	365,395,278
Domains	54,220	7,252	7,530	69,002
Web clusters	968	51	20	1,039
Programs	30	5	10	45

Table III: Breakdown of clustering and tagging results.

FEW AFFILIATE PROGRAMS CONSTITUTE THE MAJORITY

Affiliate Program		*Distinct Domains*	*Received URLs*	*Feed Volume*
RxPrm	RX–Promotion	10,585	160,521,810	24.92%
Mailn	Mailien	14,444	69,961,207	23.49%
PhEx	Pharmacy Express	14,381	69,959,629	23.48%
EDEx	ED Express	63	1,578	0.01%
ZCashPh	ZedCash (Pharma)	6,976	42,282,943	14.54%
DrMax	Dr. Maxman	5,641	32,184,860	10.95%
Grow	Viagrow	382	5,210,668	1.68%
USHC	US HealthCare	167	3,196,538	1.31%
MaxGm	MaxGentleman	672	1,144,703	0.41%
VgREX	VigREX	39	426,873	0.14%
Stud	Stud Extreme	42	68,907	0.03%
ManXt	ManXtenz	33	50,394	0.02%
GlvMd	GlavMed	2,933	28,313,136	10.32%
OLPh	Online Pharmacy	2,894	17,226,271	5.16%
Eva	EvaPharmacy	11,281	12,795,646	8.7%
WldPh	World Pharmacy	691	10,412,850	3.55%

WHAT GETS SOLD

Supplier	*Item*	*Origin*	*Affiliate Programs*
Aracoma Drug	Orange bottle of tablets (pharma)	WV, USA	ClFr
Combitic Global Caplet Pvt. Ltd.	Blister-packed tablets (pharma)	Delhi, India	GlvMd
M.K. Choudhary	Blister-packed tablets (pharma)	Thane, India	OLPh
PPW	Blister-packed tablets (pharma)	Chennai, India	PhEx, Stmul, Trust, ClFr
K. Sekar	Blister-packed tablets (pharma)	Villupuram, India	WldPh
Rhine Inc.	Blister-packed tablets (pharma)	Thane, India	RxPrm, DrgRev
Supreme Suppliers	Blister-packed tablets (pharma)	Mumbai, India	Eva
Chen Hua	Small white plastic bottles (herbal)	Jiangmen, China	Stud
Etech Media Ltd	Novelty-sized supplement (herbal)	Christchurch, NZ	Staln
Herbal Health Fulfillment Warehouse	White plastic bottle (herbal)	MA, USA	Eva
MK Sales	White plastic bottle (herbal)	WA, USA	GlvMd
Riverton, Utah shipper	White plastic bottle (herbal)	UT, USA	DrMax, Grow
Guo Zhonglei	Foam-wrapped replica watch	Baoding, China	Dstn, UltRp

Table VI: List of product suppliers and associated affiliate programs and/or store brands.

ACQUIRING BANKS

Bank Name	*BIN*	*Country*	*Affiliate Programs*
Azerigazbank	404610	Azerbaijan	GlvMd, RxPrm, PhEx, Stmul, RxPnr, WldPh
B&N	425175	Russia	ASR
B&S Card Service	490763	Germany	MaxGm
Borgun Hf	423262	Iceland	Trust
Canadian Imperial Bank of Commerce	452551	Canada	WldPh
Cartu Bank	478765	Georgia	DrgRev
DnB Nord (Pirma)	492175	Latvia	Eva, OLPh, USHC
Latvia Savings	490849	Latvia	EuSft, OEM, WchSh, Royal, SftSl
Latvijas Pasta Banka	489431	Latvia	SftSl
St. Kitts & Nevis Anguilla National Bank	427852	St. Kitts & Nevis	DmdRp, VgREX, Dstn, Luxry, SwsRp, OneRp
State Bank of Mauritius	474140	Mauritius	DrgRev
Visa Iceland	450744	Iceland	Staln
Wells Fargo	449215	USA	Green
Wirecard AG	424500	Germany	ClFr

Table V: Merchant banks authorizing or settling transactions for spam-advertised purchases, their Visa-assigned Bank Identification Number (BIN), their location, and the abbreviation used in Table IV for affiliate program and/or store brand.

SO HOW MUCH ARE SPAMBOTS MAKING?

- To understand, we would have to know:
  - Order volume (how much is sold as a result of an affiliate program over time?)
  - Purchasing behavior (what are people buying?)

- Prior understanding was vague at best

AFFILIATE PROFIT

Affiliate Program	orders/month	*Spamalytics* single order	*Spamalytics* rev/month	Min product price single order	Min product price rev/month	Basket-weighted average single order	Basket-weighted average rev/month
33drugs	9,862	$100	$980,000	$45.00	$440,000	$57.25	$560,000
4RX	8,001	$100	$800,000	$34.50	$280,000	$95.00	$760,000
EuroSoft	22,776	N/A	N/A	$26.50	$600,000	$84.50	$1,900,000
EvaPharmacy	26,962	$100	$2,700,000	$50.50	$1,300,000	$90.00	$2,400,000
GlavMed	17,933	$100	$1,800,000	$54.00	$970,000	$57.00	$1,000,000
Online Pharmacy	5,856	$100	$590,000	$37.00	$220,000	$58.00	$340,000
Pharmacy Express	7,933	$100	$790,000	$51.00	$410,000	$58.75	$460,000
Royal Software	13,483	N/A	N/A	$55.25	$750,000	$133.75	$1,800,000
Rx–Promotion	6,924	$100	$690,000	$45.00	$310,000	$57.25	$400,000
SoftSales	1,491	N/A	N/A	$20.00	$30,000	$134.50	$200,000

Table 4: Estimated monthly order volume, average purchase price, and monthly revenue (in dollars) per affiliate program using three different per-order price approximations.

Over 100k orders/month in this dataset alone

Some have guessed that "spammers make little money at all"

So who's actually buying this junk?

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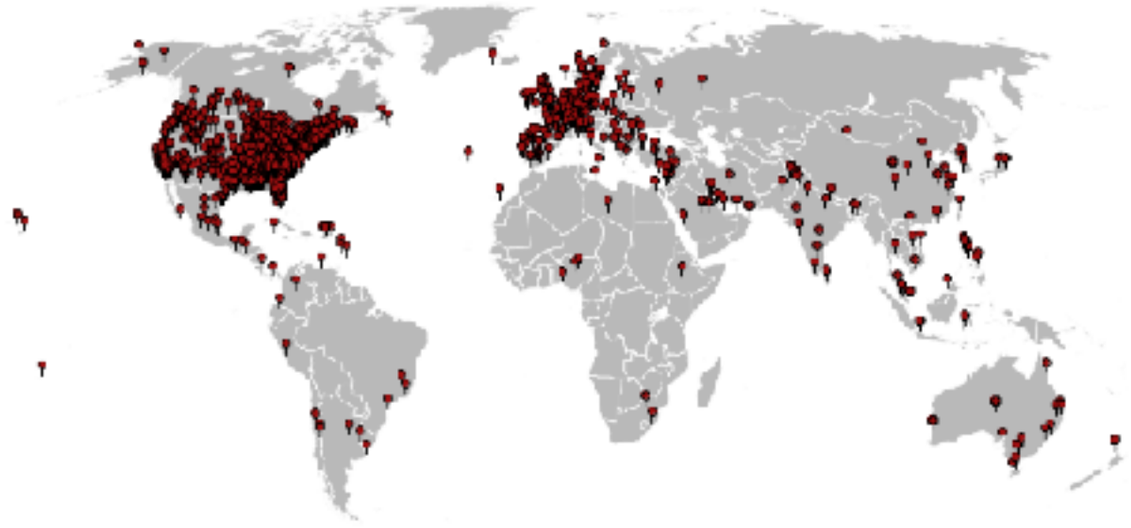

Figure 6: The geographic distribution of those who added an item to their shopping cart.

Country	Visits	Cart Additions	Added Product
United States	517,793	3,707	0.72%
Canada	50,234	218	0.43%
Philippines	42,441	39	0.09%
United Kingdom	39,087	131	0.34%
Spain	26,968	59	0.22%
Malaysia	26,661	31	0.12%
France	18,541	37	0.20%
Germany	15,726	56	0.36%
Australia	15,101	86	0.57%
India	10,835	17	0.16%
China	8,924	30	0.34%
Netherlands	8,363	21	0.25%
Saudi Arabia	8,266	36	0.44%
Mexico	7,775	17	0.22%
Singapore	7,586	17	0.22%

Table 2: The top 15 countries and the percentage of visitors who added an item to their shopping cart.

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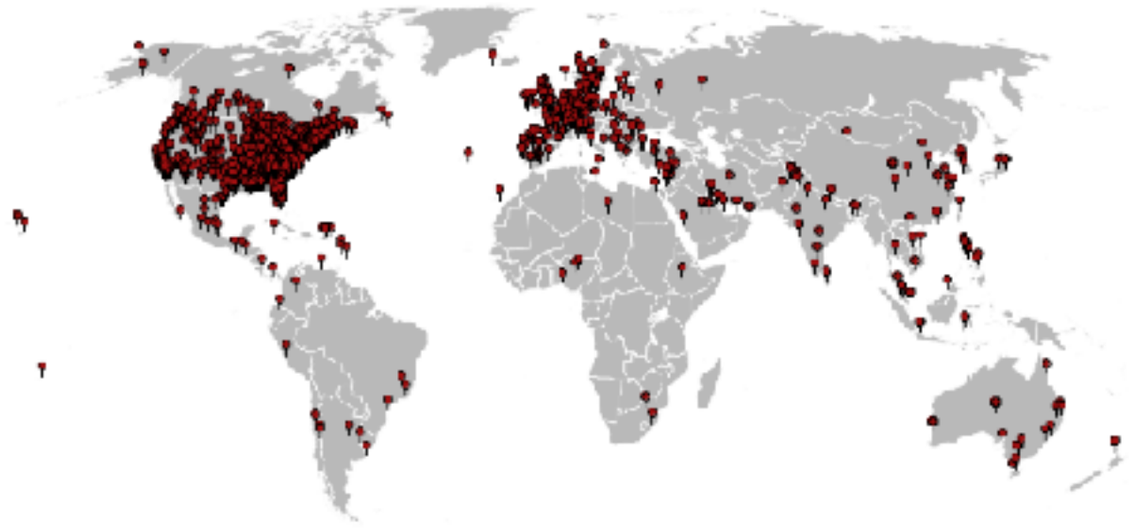

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Stop buying this junk!

What are you buying?

Product	Quantity	Min order
Generic Viagra	568	$78.80
Cialis	286	$78.00
Cialis/Viagra Combo Pack	172	$74.95
Viagra Super Active+	121	$134.80
Female (pink) Viagra	119	$44.00
Human Growth Hormone	104	$83.95
Soma (Carisoprodol)	99	$94.80
Viagra Professional	87	$139.80
Levitra	83	$100.80
Viagra Super Force	81	$88.80
Cialis Super Active+	72	$172.80
Amoxicillin	47	$35.40
Lipitor	38	$14.40
Ultram	38	$45.60
Tramadol	36	$82.80
Prozac	35	$19.50
Cialis Professional	33	$176.00
Retin A	31	$47.85

“Why do you rob banks?”

“Because that’s where the money is”

Why does the emergence of the underground economy matter?

- Many of the centralized components of these networks get pursued and shut down

- Markets lead to efficiencies and specializations
  - Lowers barrier to entry: only need a single skill
  - Some underground market activities are legal

- Competition spurs innovation
  - Accelerates the arms race
  - Defenders must assume a more pessimistic threat model

- Facilitates non-$ Internet attacks
  - Provides actors (political, nation-state) with cheap attack components

WHY STUDYING IT MATTERS

And why *continuing* to study it matters

- Like any complex system, these markets can themselves be infiltrated
  - Some research on infiltrating affiliate programs & botnets, taking over C&C

- Can identify choke points
  - Many hosting services have been shut down
  - Draws attention to shady banks
  - Draws attention to shady doctors
    - Early spambot had one doctor writing 1500+ prescriptions per day

SOME FINAL THOUGHTS ON SECURITY

- It's difficult
- It requires demystification of the services you use, deep knowledge of the tools you use, and adherence to a set of **design principles**
- It requires vigilance—attackers won't rest, so neither can we

SOME FINAL THOUGHTS ON SECURITY

- It's fun!
- Constant race for innovation, often surprising turns
  - But sometimes just frustrating mistakes
- It permeates all aspects of computer science, system building, human interaction, ….

WHAT I WANT FROM ALL OF YOU

WHAT I WANT FROM ALL OF YOU

You are now responsible.

WHAT I WANT FROM ALL OF YOU

You are now responsible.

Bring copious amounts of

thoroughness,
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ethics,
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to your future endeavors.

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