ISOLATION DEFENSES

GRAD SEC

OCT 03 2017

ISOLATION

Running untrusted code in a trusted environment

Setting

Possibly with multiple tenants

- OS: users / processes
- Browser: webpages / browser extensions
- Cloud: virtual machines (VMs)

Threat model

Execution begins in the trusted environment

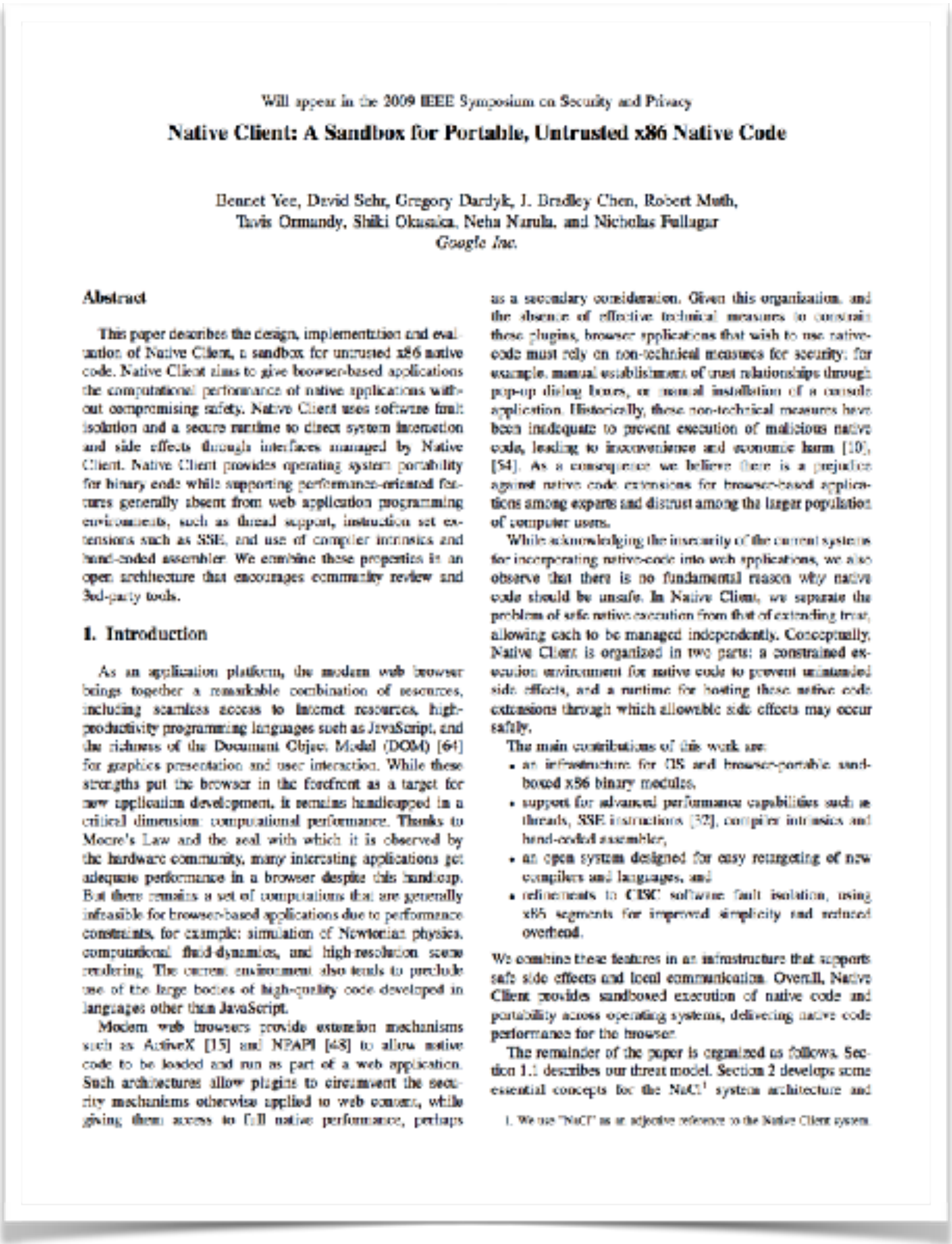
Attacker can provide arbitrary code and data

Attacker's goal is to *run* arbitrary code or exfiltrate data

Security goal

Restrict the set of actions that an attacker can make

TODAY'S PAPERS


Will appear in the 2009 IEEE Symposium on Security and Privacy

Native Client: A Sandbox for Portable, Untrusted x86 Native Code

Bennet Yee, David Sehr, Gregory Dardyk, J. Bradley Chen, Robert Muth,
Tavis Ormandy, Shiki Okasaka, Neha Narula, and Nicholas Fullagar
Google Inc.

Abstract

1. Introduction


The Security Architecture of the Chromium Browser

Adam Barth — UC Berkeley
Collin Jackson — Stanford University
Charles Reis — University of Washington
Google Chrome Team — Google Inc.

ABSTRACT

1. INTRODUCTION


What have I done
to deserve this?

SANDBOXES

Execution environment that restricts what an application running in it can do

NaCl's restrictions

Takes arbitrary x86, runs it in a sandbox in a browser

- Restrict applications to using a narrow API
- Data integrity: No reads/writes outside of sandbox
- No unsafe instructions
- CFI

Chromium's restrictions

Runs each webpage's rendering engine in a sandbox

- Restrict rendering engines to a narrow "kernel" API
- Data integrity: No reads/writes outside of sandbox (incl. the desktop and clipboard)

NACL CONSTRAINTS

C1	Once loaded into the memory, the binary is not writable, enforced by OS-level protection mechanisms during execution.
C2	The binary is statically linked at a start address of zero, with the first byte of text at 64K.
C3	All indirect control transfers use a `nacljmp` pseudo-instruction (defined below).
C4	The binary is padded up to the nearest page with at least one `hlt` instruction (0xf4).
C5	The binary contains no instructions or pseudo-instructions overlapping a 32-byte boundary.
C6	All *valid* instruction addresses are reachable by a fall-through disassembly that starts at the load (base) address.
C7	All direct control transfers target valid instructions.

Applied to all untrusted binaries

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What if we *didn't* have this?

Attacker could overwrite the binary with code (e.g., as a result of a wget)

NaCl would have to statically analyze that new code

What if we *only* had this?

Load binary with invalid instructions

ROP to make the binary writable

NACL CONSTRAINTS

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- **C7** All direct control transfers target valid instructions.

What if we *didn't* have this?

Would render C5, C6, C7 useless

⟹ Could not determine control transfer targets

What if we *only* had this?

Alone, it is not checking for or preventing anything

NACL CONSTRAINTS

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nacljmp (SFI)

jmp %eax

First byte is 64K (C2)

and %eax, 0xffffffe0
jmp (%eax)

What if we *didn't* have this?

Attacker could potentially jump anywhere
ROP, code injection

What if we *only* had this?

C1 necessary; C2 ensures these are instructions

C7 ensures that what it's jumping to is valid

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What if we *didn't* have this?

Execution would continue beyond the executable itself

Could start to run data

What if we *only* had this?

Provides no guarantees about what's in the code itself

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C7	All direct control transfers target valid instructions.

What if we *didn't* have this?

Would render nacljmp useless

⟹ Wouldn't know what exactly we're jumping to

What if we *only* had this?

Provides no guarantees about what we are jumping to

NACL CONSTRAINTS

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What if we *didn't* have this?

Could not perform disassembly

⟹ Could not infer what instructions are called

What if we *only* had this?

C1 still breaks it

Doesn't say you can't also hit invalid instructions

NACL CONSTRAINTS

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What if we *didn't* have this?

Invalid instructions!

$\Longrightarrow$ Arbitrary syscalls, interrupts, loads, returns, …

What if we *only* had this?

C1 still breaks it; C4: could execute beyond the binary

C2, C3, C5, C6 are needed to get to C7

NACL VALIDATOR

C2: Known entry point

C7: No invalid instructions

C5: No invalid alignments

C3: Only use nacljmp

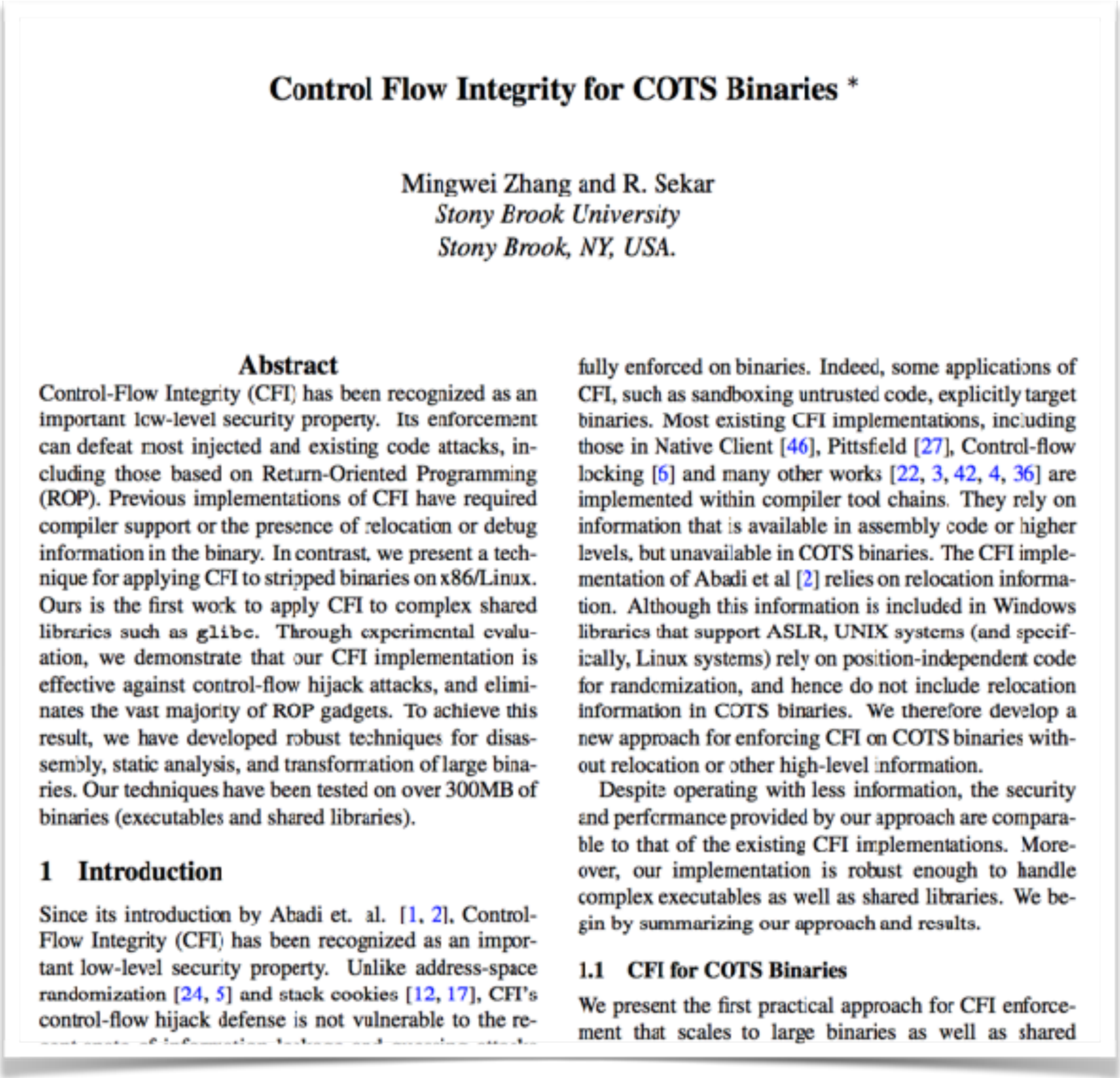
Common disassembly techniques

```
// TextLimit = the upper text address limit
// Block(IP) = 32-byte block containing IP
// StartAddr = list of inst start addresses
// JumpTargets = set of valid jump targets

// Part 1: Build StartAddr and JumpTargets
IP = 0; icount = 0; JumpTargets = { }
while IP <= TextLimit:
  if inst_is_disallowed(IP):
    error "Disallowed instruction seen"
  StartAddr[icount++] = IP
  if inst_overlaps_block_size(IP):
    error "Block alignment failure"
  if inst_is_indirect_jump_or_call(IP):
    if !is_2_inst_nacl_jmp_idiom(IP) or
      icount < 2 or
      Block(StartAddr[icount-2]) != Block(IP):
      error "Bad indirect control transfer"
  else
    // Note that indirect jmps are inside
    // a pseudo-inst and bad jump targets
    JumpTargets = JumpTargets + { IP }
  // Proceed to the fall-through address
  IP += InstLength(IP)

// Part 2: Detect invalid direct transfers
for I = 0 to length(StartAddr)-1:
  IP = StartAddr[I]
  if inst_is_direct_jump_or_call(IP):
    T = direct_jump_target(IP)
    if not(T in [0:TextLimit))
       or not(T in JumpTargets):
      error "call/jmp to invalid address"
```

DISASSEMBLY



Control Flow Integrity for COTS Binaries *

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Stony Brook, NY, USA.

Abstract

Control-Flow Integrity (CFI) has been recognized as an important low-level security property. Its enforcement can defeat most injected and existing code attacks, including those based on Return-Oriented Programming (ROP). Previous implementations of CFI have required compiler support or the presence of relocation or debug information in the binary. In contrast, we present a technique for applying CFI to stripped binaries on x86/Linux. Ours is the first work to apply CFI to complex shared libraries such as `glibc`. Through experimental evaluation, we demonstrate that our CFI implementation is effective against control-flow hijack attacks, and eliminates the vast majority of ROP gadgets. To achieve this result, we have developed robust techniques for disassembly, static analysis, and transformation of large binaries. Our techniques have been tested on over 300MB of binaries (executables and shared libraries).

1 Introduction

Since its introduction by Abadi et. al. [1, 2], Control-Flow Integrity (CFI) has been recognized as an important low-level security property. Unlike address-space randomization [24, 5] and stack cookies [12, 17], CFI's control-flow hijack defense is not vulnerable to the re- fully enforced on binaries. Indeed, some applications of CFI, such as sandboxing untrusted code, explicitly target binaries. Most existing CFI implementations, including those in Native Client [46], Pittsfield [27], Control-flow locking [6] and many other works [22, 3, 42, 4, 36] are implemented within compiler tool chains. They rely on information that is available in assembly code or higher levels, but unavailable in COTS binaries. The CFI implementation of Abadi et al [2] relies on relocation information. Although this information is included in Windows libraries that support ASLR, UNIX systems (and specifically, Linux systems) rely on position-independent code for randomization, and hence do not include relocation information in COTS binaries. We therefore develop a new approach for enforcing CFI on COTS binaries without relocation or other high-level information.

Despite operating with less information, the security and performance provided by our approach are comparable to that of the existing CFI implementations. Moreover, our implementation is robust enough to handle complex executables as well as shared libraries. We begin by summarizing our approach and results.

1.1 CFI for COTS Binaries

We present the first practical approach for CFI enforcement that scales to large binaries as well as shared

<u>Linear disassembly</u>

Start at instruction i

i += inst_len(i)

Leaves gaps if there are variable-length inst's, data, bad alignment…

<u>Recursive disassembly</u>

Set of entry points E

Start at entry point i

if i is a jmp:

add its target to E

i += inst_len(i)

Goal: CFI without access to code:
How do you infer the control flow graph?

NACL VALIDATOR

C2: Known entry point

C7: No invalid instructions

C5: No invalid alignments

C3: Only use nacljmp

Theorem: StartAddr contains all addresses that can be reached from an instruction with address in StartAddr.

```
// TextLimit = the upper text address limit
// Block(IP) = 32-byte block containing IP
// StartAddr = list of inst start addresses
// JumpTargets = set of valid jump targets

// Part 1: Build StartAddr and JumpTargets
IP = 0; icount = 0; JumpTargets = { }
while IP <= TextLimit:
  if inst_is_disallowed(IP):
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// Part 2: Detect invalid direct transfers
for I = 0 to length(StartAddr)-1:
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  if inst_is_direct_jump_or_call(IP):
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       or not(T in JumpTargets):
      error "call/jmp to invalid address"
```

NACL VALIDATOR: PROOF

Theorem: StartAddr contains all addresses that can be reached from an instruction with address in StartAddr.

case 1: IP is reached by falling through from A. This implies that IP is InstAddr(A) + InstLength(A). But this address would have been in S from part 1 of the construction. Contradiction.

case 2: IP is reached by a direct jump or call from an instruction A in S. Then IP must be in JumpTargets, a condition checked by part 2 of the construction. Observe that JumpTargets is a subset of S, from part 1 of the construction. Therefore IP must be in S. Contradiction.

case 3: IP is reached by an indirect transfer from an instruction at A in S. Since the instruction at A is an indirect call or jump, any execution of A always immediately follows the execution of an `and`. After the `and` the computed address is aligned 0 mod 32. Since no instruction can straddle a 0 mod 32 boundary, every 0 mod 32 address in [0, TextLimit) must be in S. Hence IP is in S. Contradiction.

ACTUALLY DOING THINGS WITH NACL

C2	The binary is statically linked at a start address of zero, with the first byte of text at 64K.

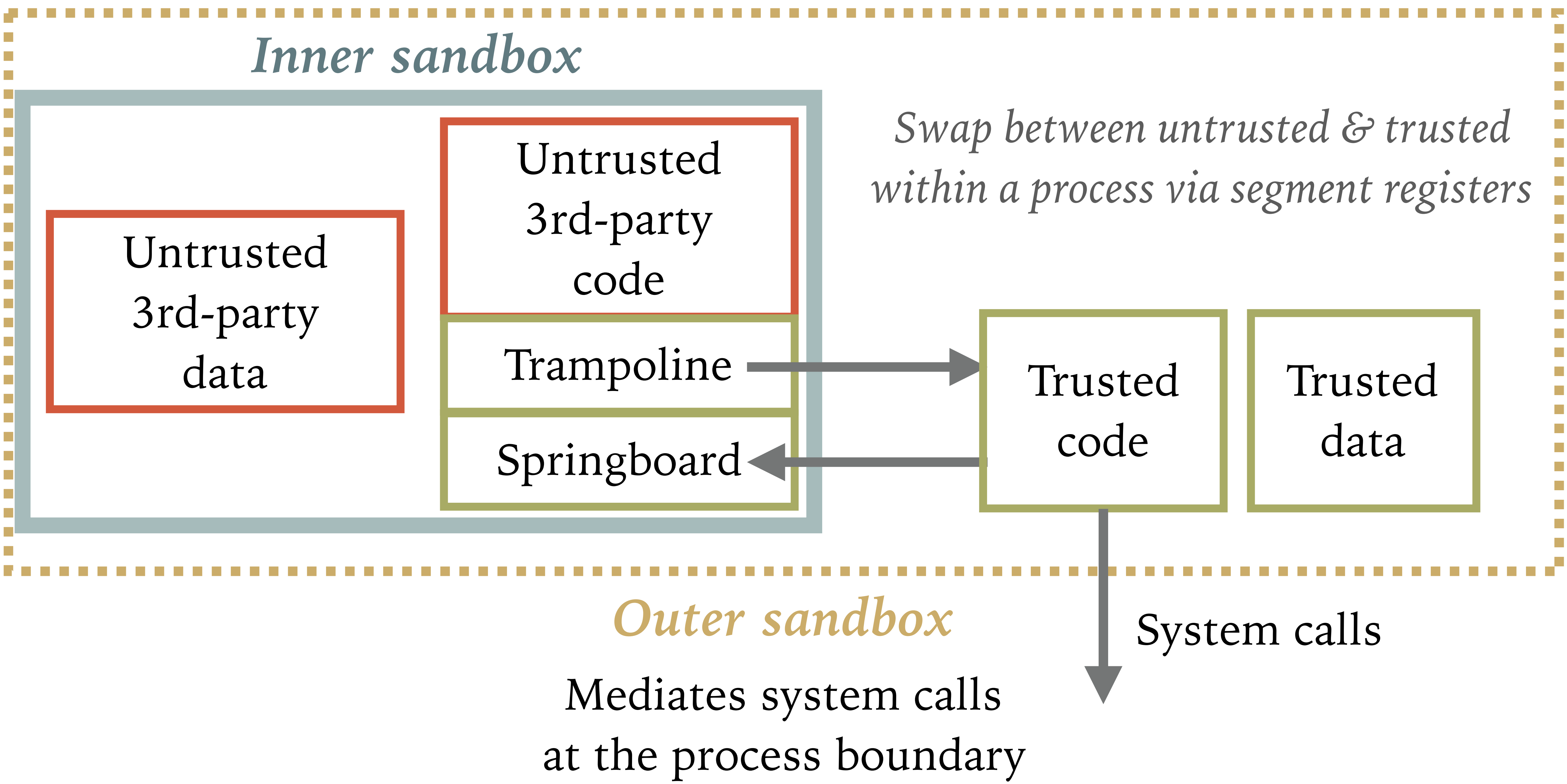
First 4KB: Unreadable, unwritable (detect NULL pointers)

Remaining 60KB: **trusted** trampoline code (untrusted to trusted) & springboard return (trusted to untrusted)

Ensures we have a **Trusted Compute Base (TCB)** in the malicious binary

- Allowed to contain instructions that are forbidden elsewhere
- Especially `far call` to enable control transfers between untrusted user code and trusted service runtime
- Separation is handled by setting / restoring segment registers, which locate the code/text segments

NACL'S SANDBOXES



SECURITY DESIGN PRINCIPLES

Defense in depth

SECCOMP-BPF

- Linux system call enabled since 2.6.12 (2005)
  - Affected process can subsequently **only perform read, write, exit, and sigreturn system calls**
    - No support for open call: Can only use already-open file descriptors
  - **Isolates a process by limiting possible interactions**

- Follow-on work produced **seccomp-bpf**
  - **Limit process to policy-specific set of system calls**, subject to a policy handled by the kernel
    - Policy akin to *Berkeley Packet Filters (BPF)*
  - Used by *Chrome*, *OpenSSH*, *vsftpd*, and others

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The Security Architecture of the Chromium Browser

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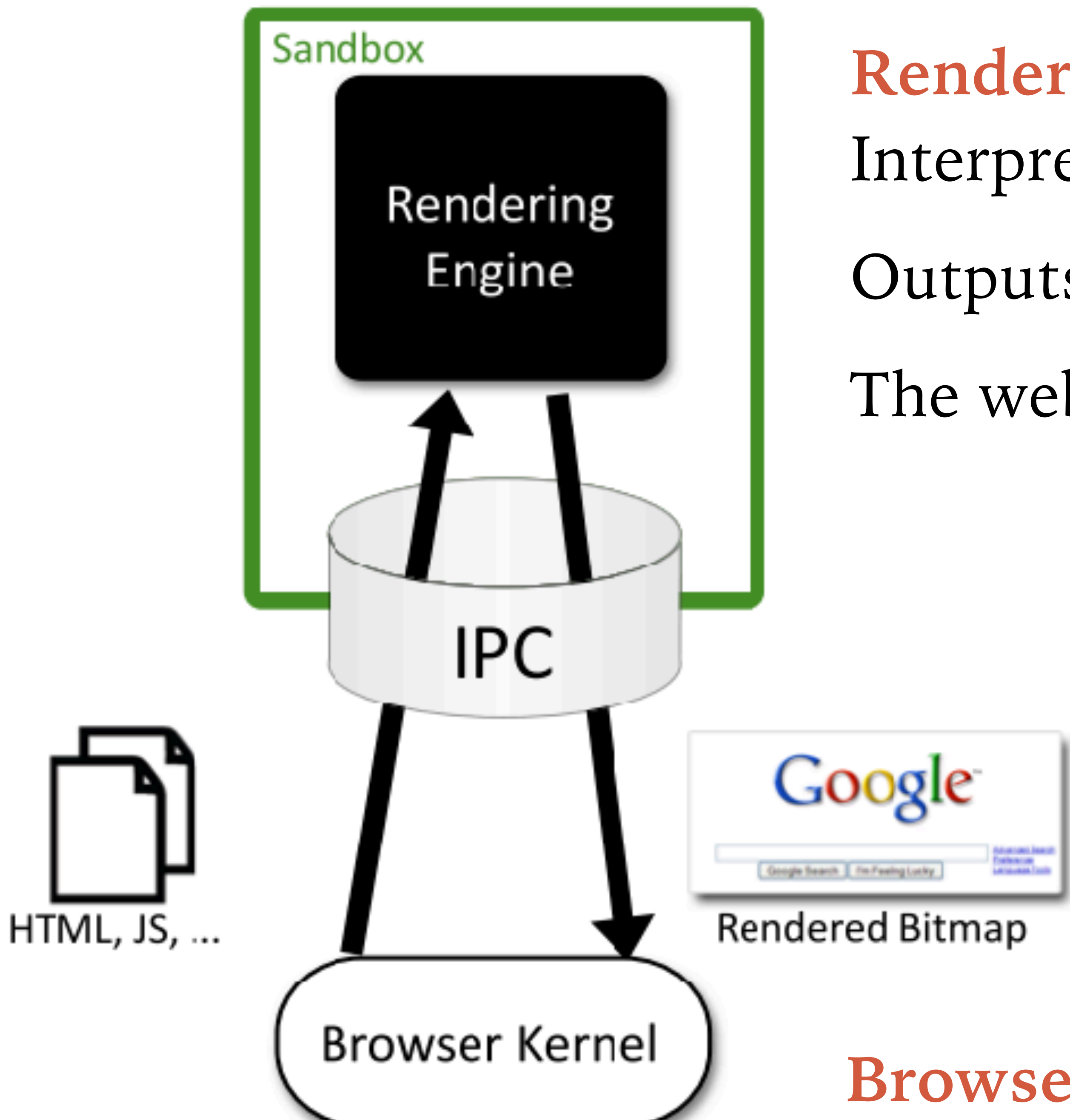
Google Chrome Team, Google Inc.

ABSTRACT

1. INTRODUCTION

CHROMIUM ARCHITECTURE



Rendering Engine:

Interprets and executes web content

Outputs rendered bitmaps

The website is the "untrusted code"

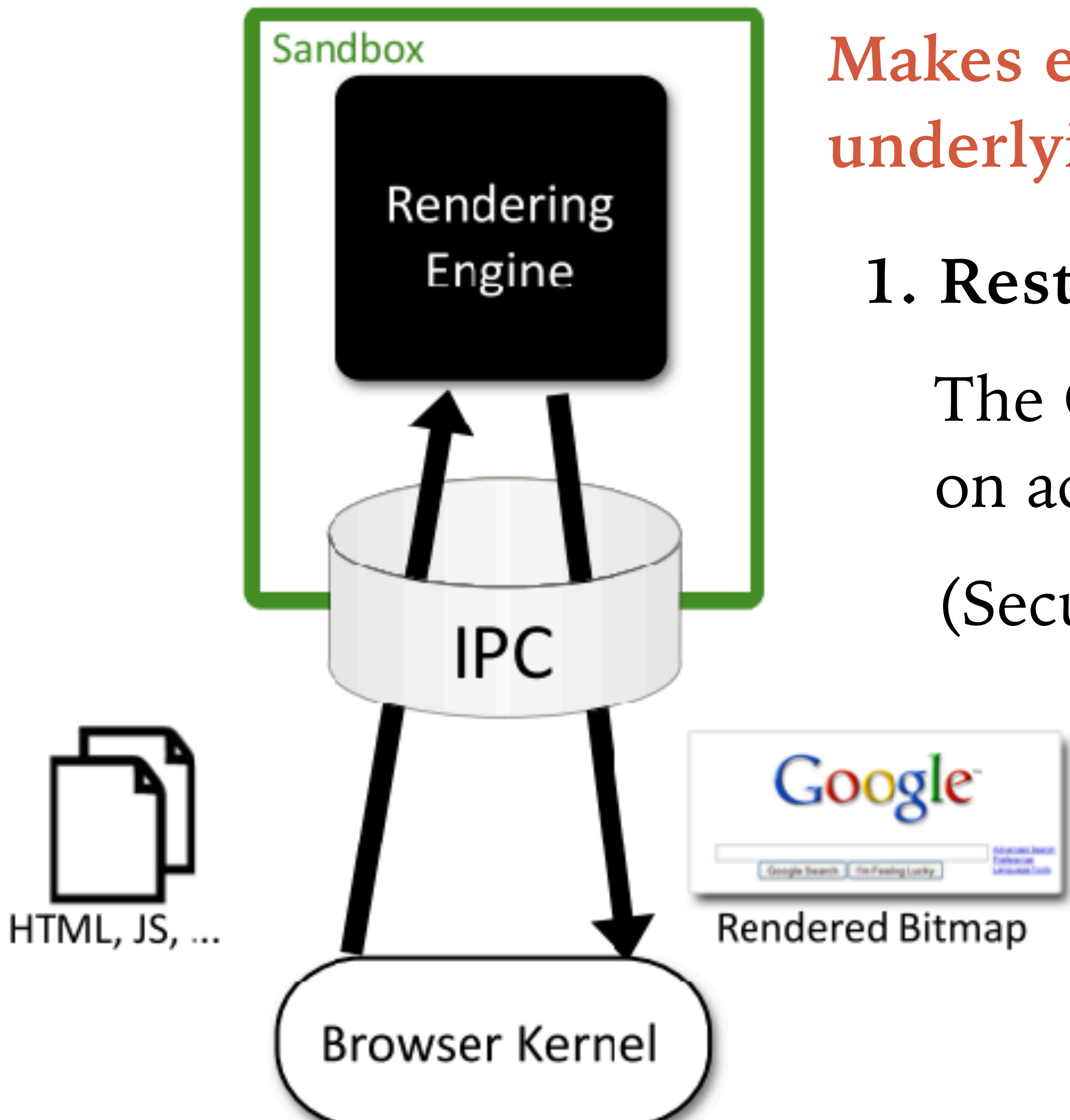
Goal: Enforce a narrow interface between the two

Browser Kernel:

Stores data (cookies, history, clipboard)

Performs all network operations

CHROMIUM'S SANDBOX



Makes extensive use of the underlying OS's primitives

1. **Restricted security token**

   The OS then provides complete mediation on access to "securable objects"

   (Security token set s.t. it fails almost always)

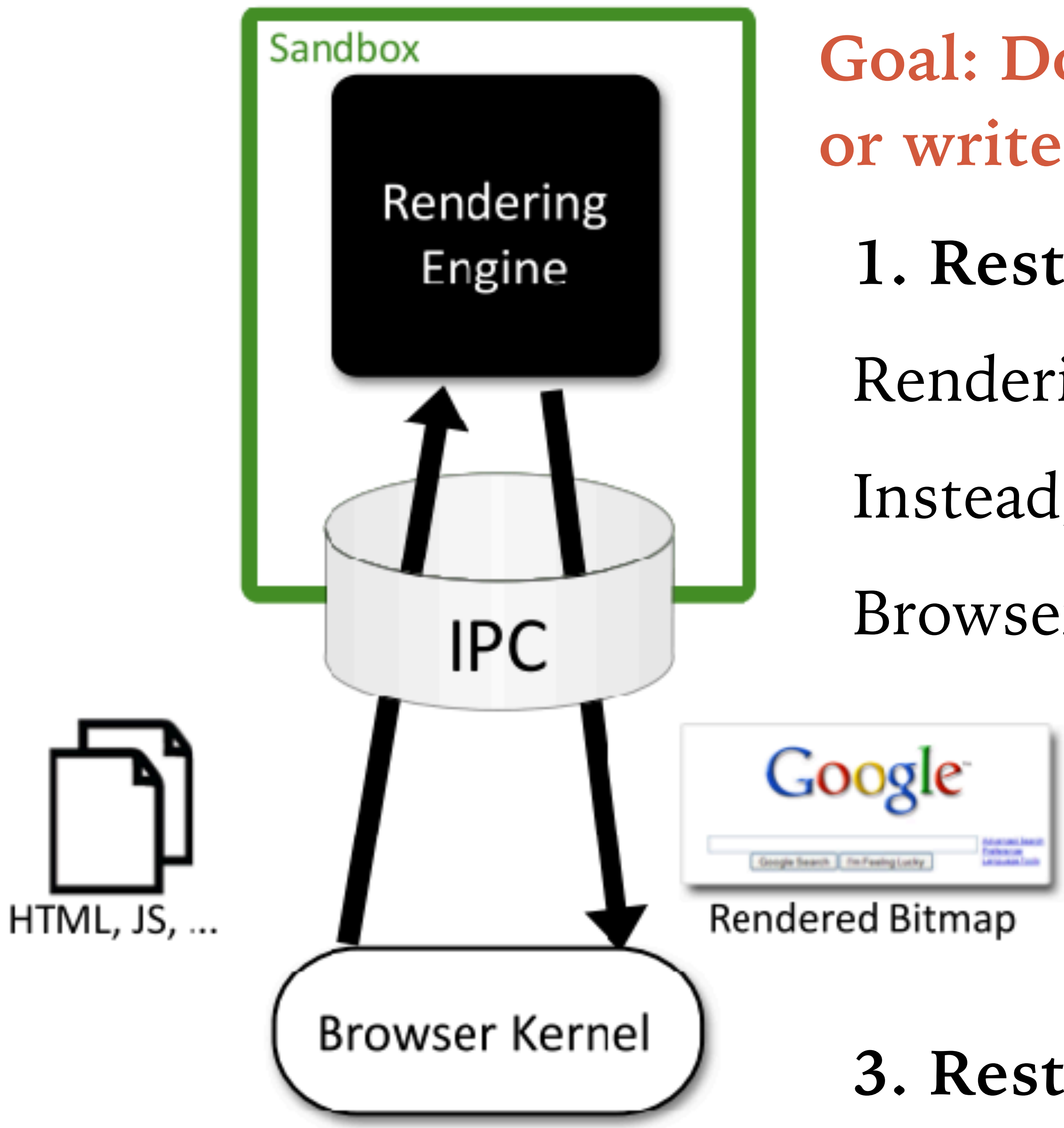
2. **Separate desktop**

   Avoid Windows API's lax security checks

3. **Windows Job Object**

   Can't fork processes; can't access clipboard

CHROMIUM'S BROWSER KERNEL INTERFACE



Goal: Do not leak the ability to read or write the user's file system

1. Restrict rendering

Rendering engine doesn't get a window handle

Instead, draws to an off-screen bitmap

Browser kernel copies this bitmap to the screen

2. Network & I/O

Rendering engine requests uploads, downloads, and file access thru BKI

3. Restrict user input

Rendering engine doesn't get user input directly

Instead, browser kernel delivers it via BKI