

Replication Prohibited

Attacking Restricted Keyways with 3D Printing

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Introduction

- Modern locks rely on intricately shaped keys and keyways to defend against known attacks
- Do 3D printed keys undermine this security?

Contributions

- Performed in depth study of the durability of 3D printed keys along with an analysis of their potential for use in attacks
- Developed an automated tool to generate the CAD models of these keys

- **Background**
 - **Basic Pin Tumbler Locks**
 - Master Keying
 - Attacks
 - Levels of Key Systems
- 3D Printing Keys
- Countermeasures
- Summary

Lock Front View



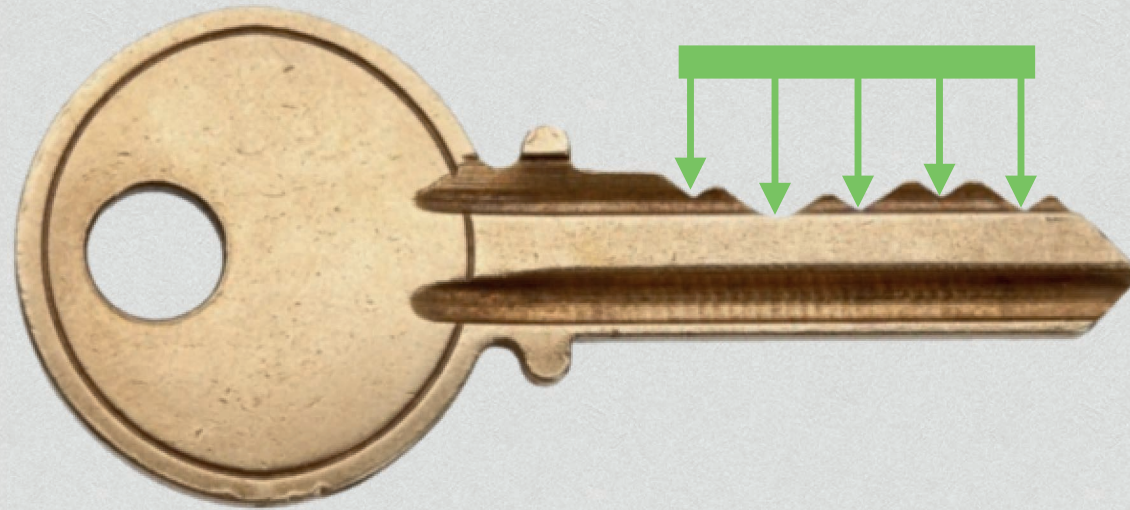
Keyway

Lock Front View



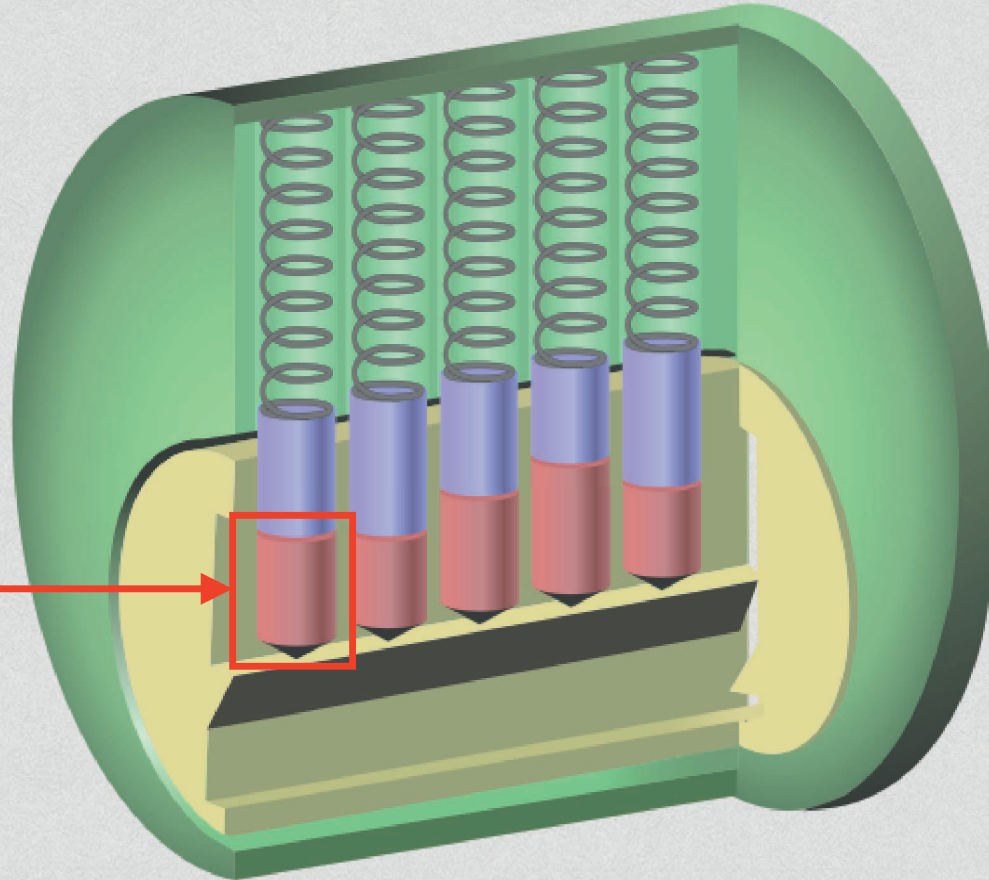
Plug

Key Side View



Cuts on a Key

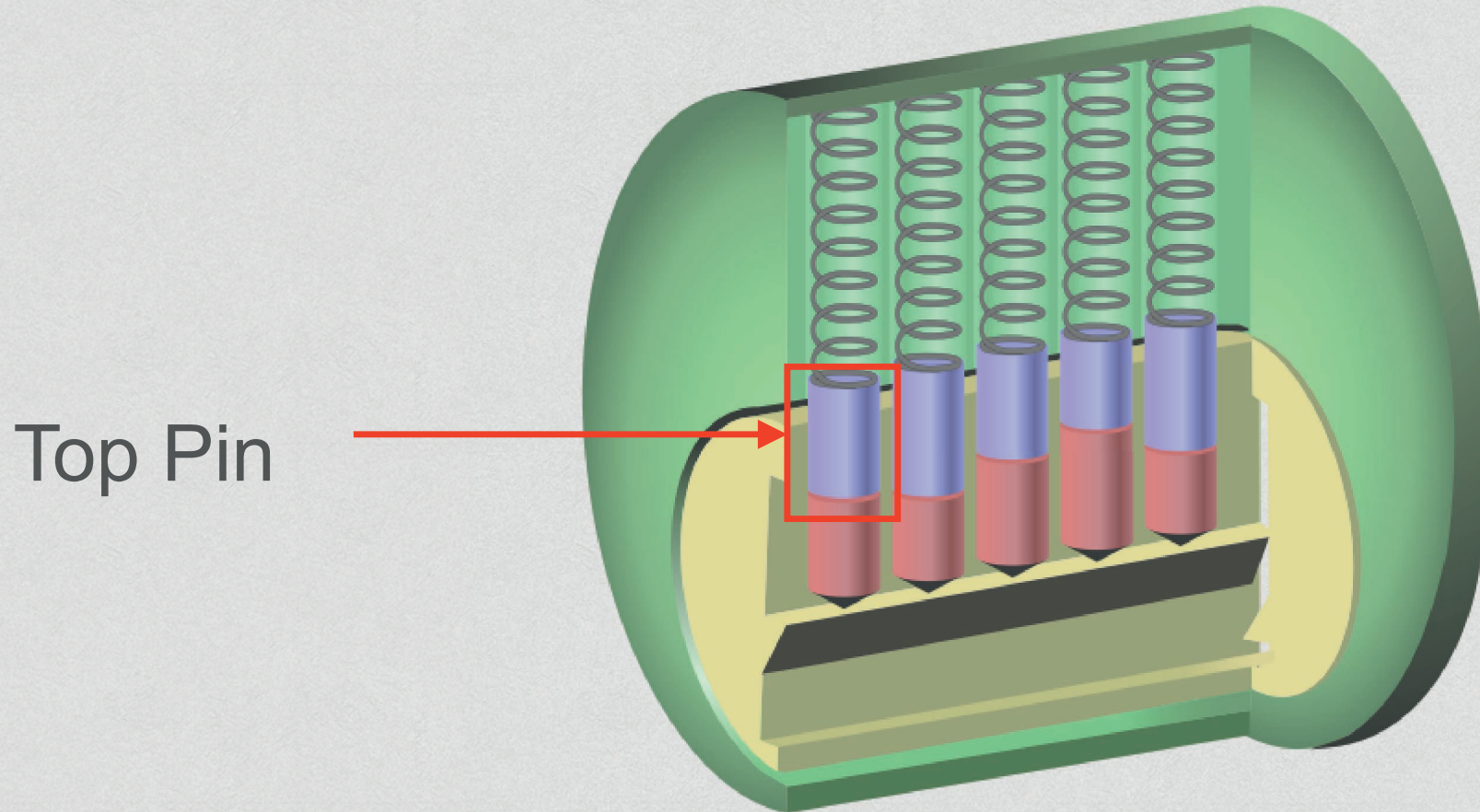
Lock Cutaway



Bottom Pin

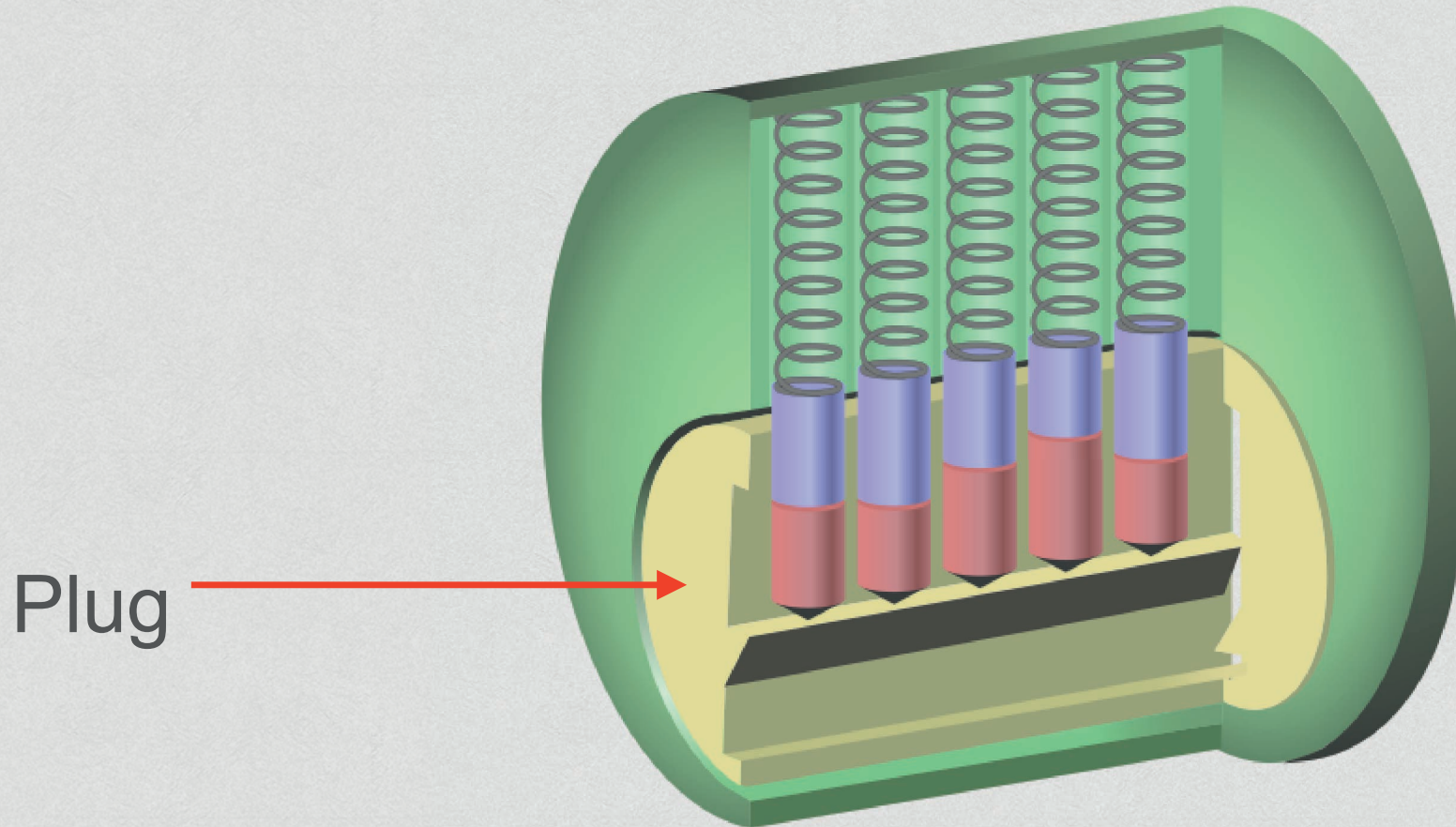
No Key Inserted

Lock Cutaway



No Key Inserted

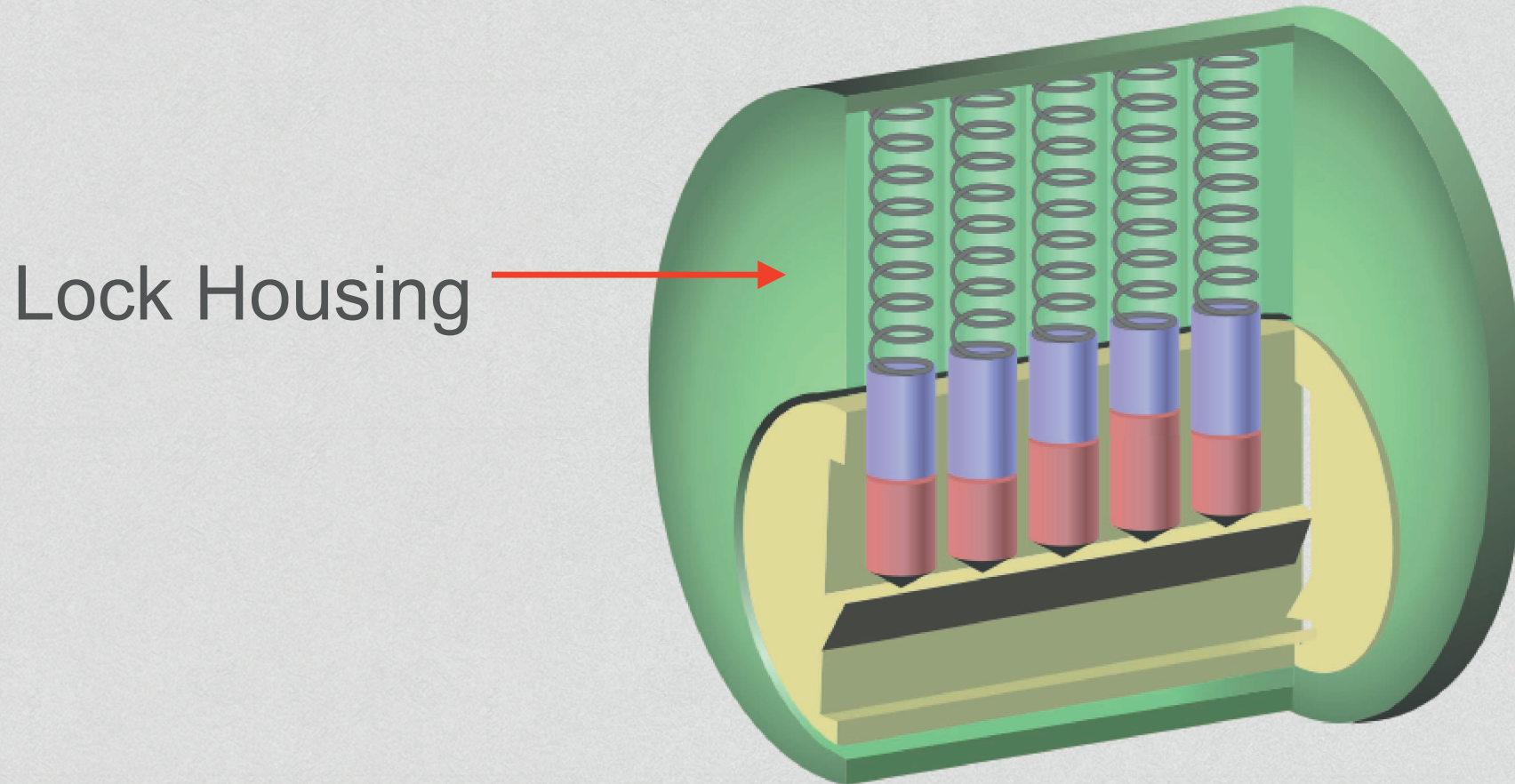
Lock Cutaway



Plug

No Key Inserted

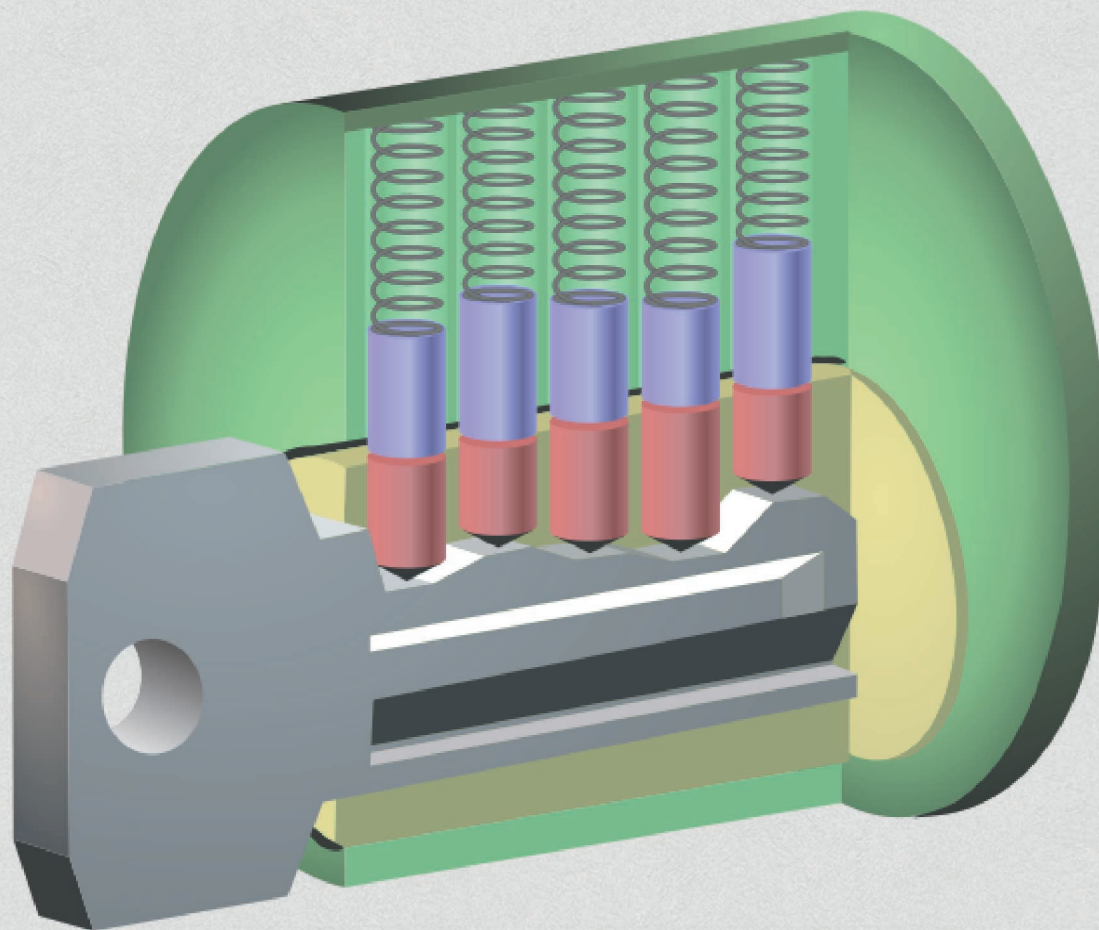
Lock Cutaway



Lock Housing

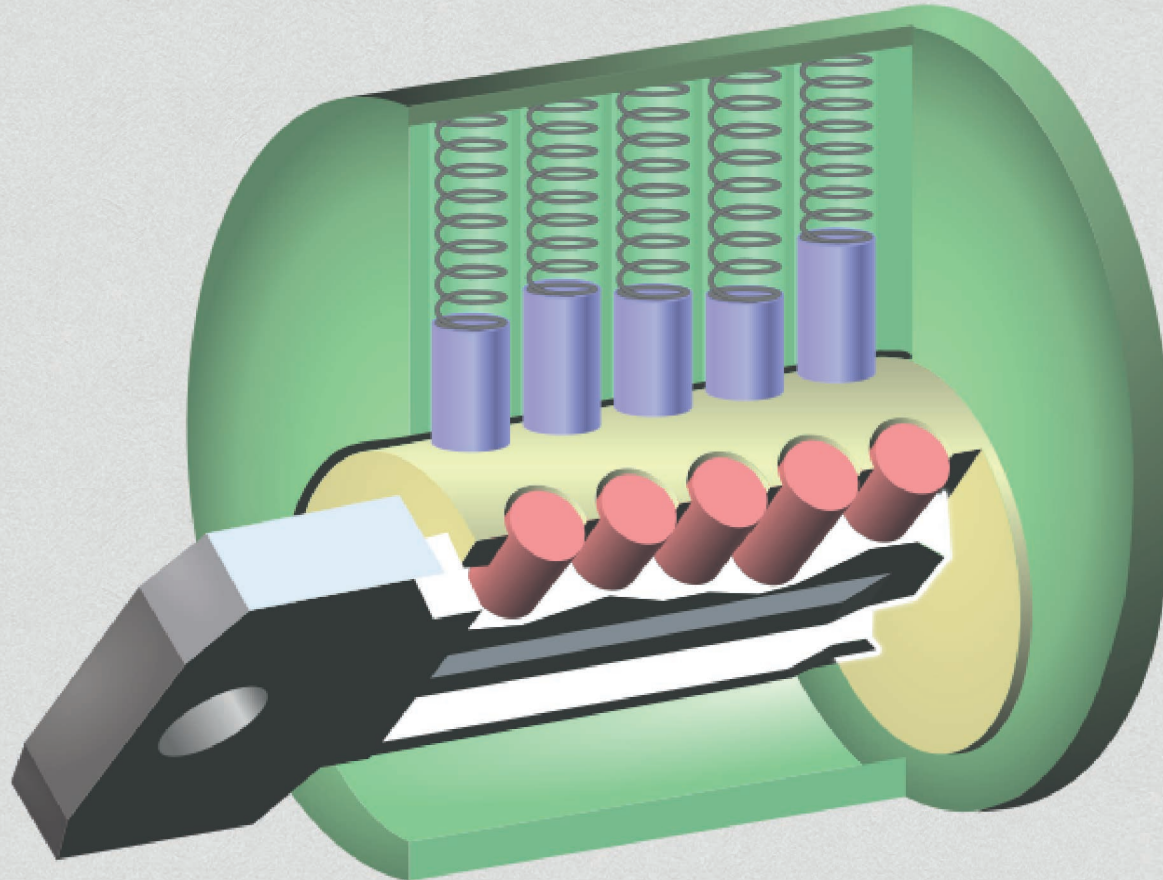
No Key Inserted

Lock Cutaway



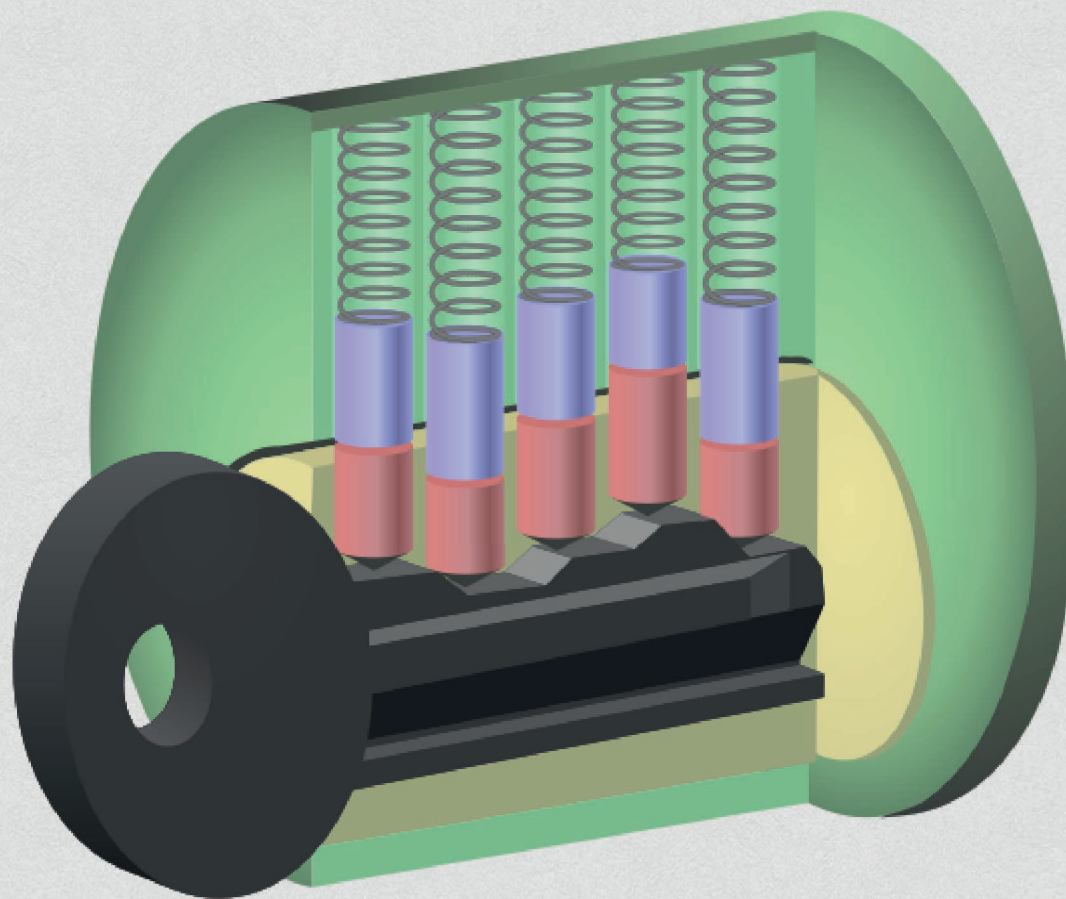
Correct Key Inserted

Lock Cutaway



Correct Key Inserted and Plug Rotated

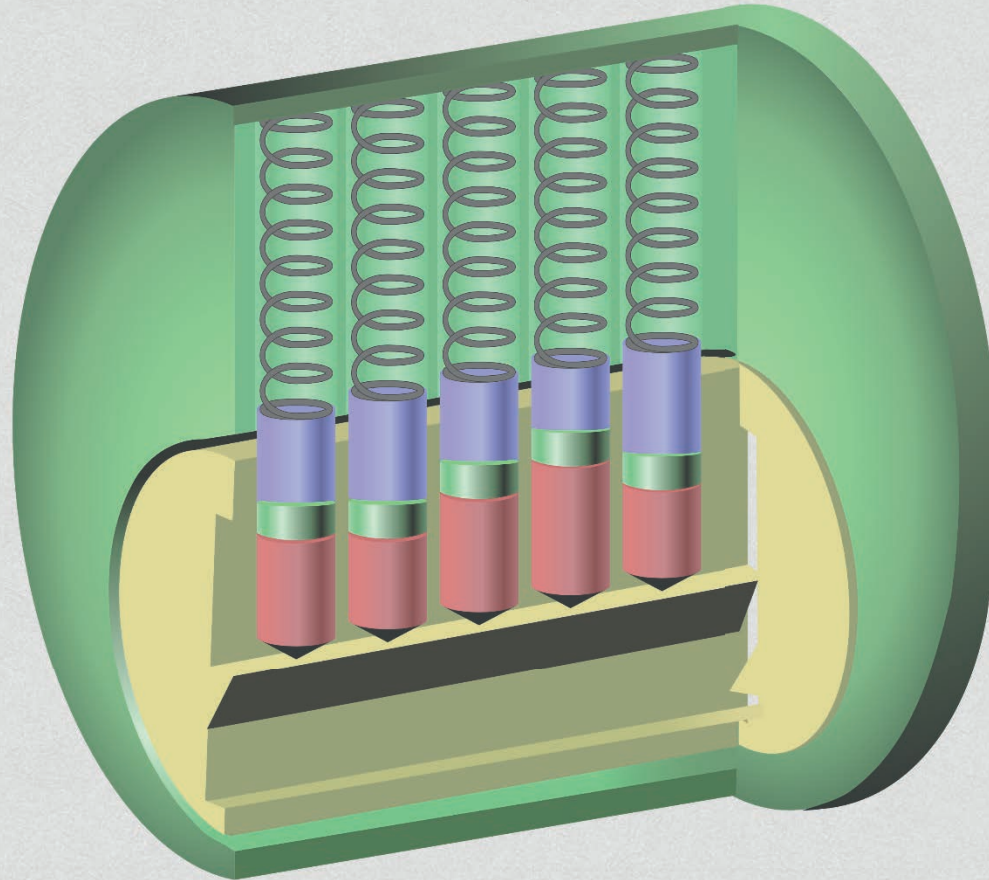
Lock Cutaway



Incorrect Key Inserted

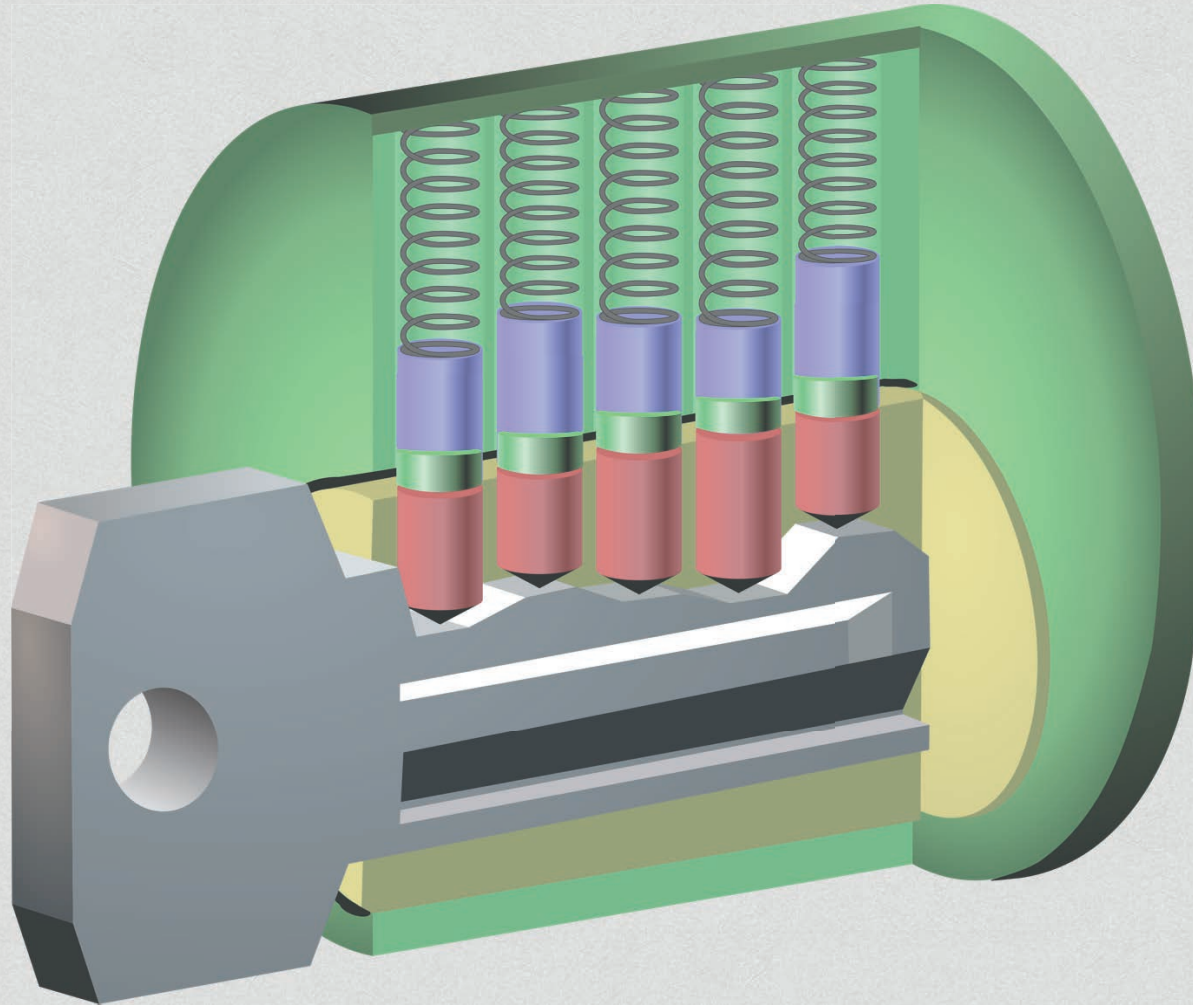
- **Background**
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Master Keyed Pin Tumbler Lock



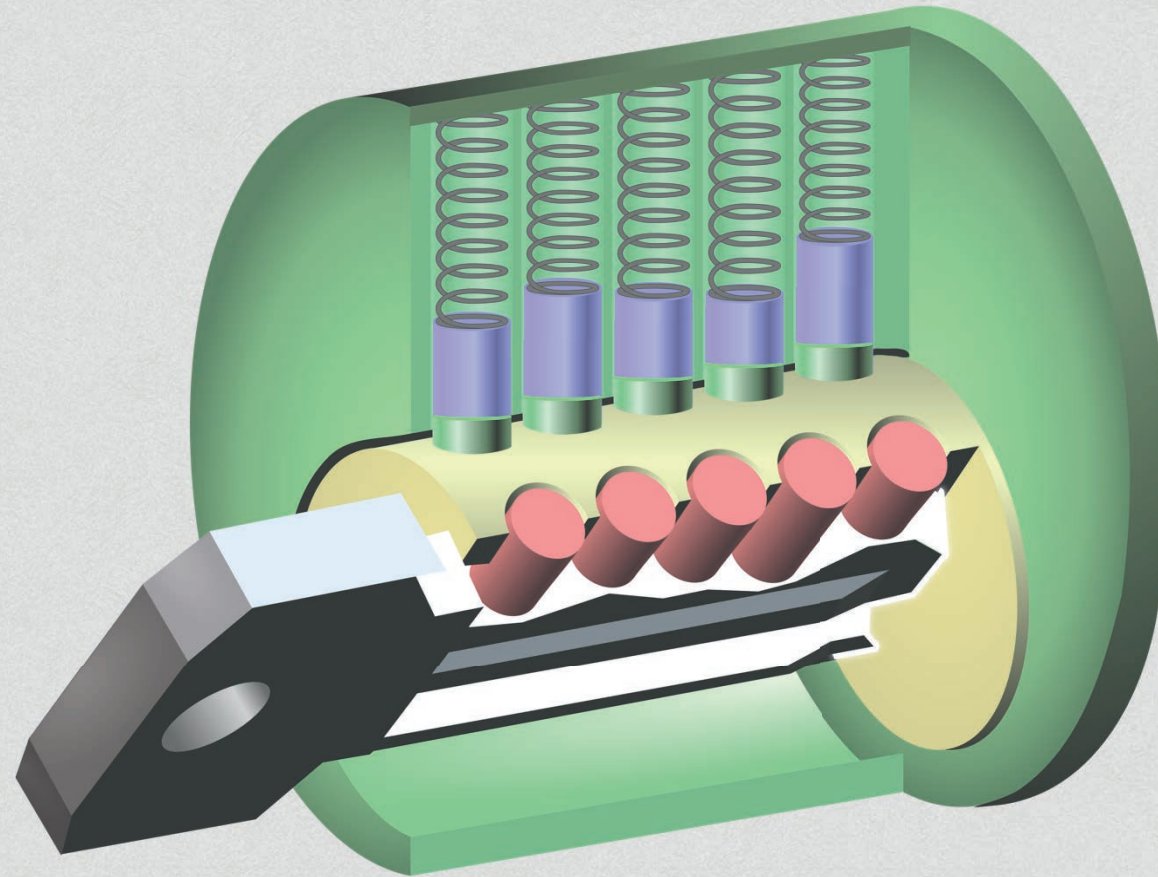
No Key Inserted

Master Keyed Pin Tumbler Lock



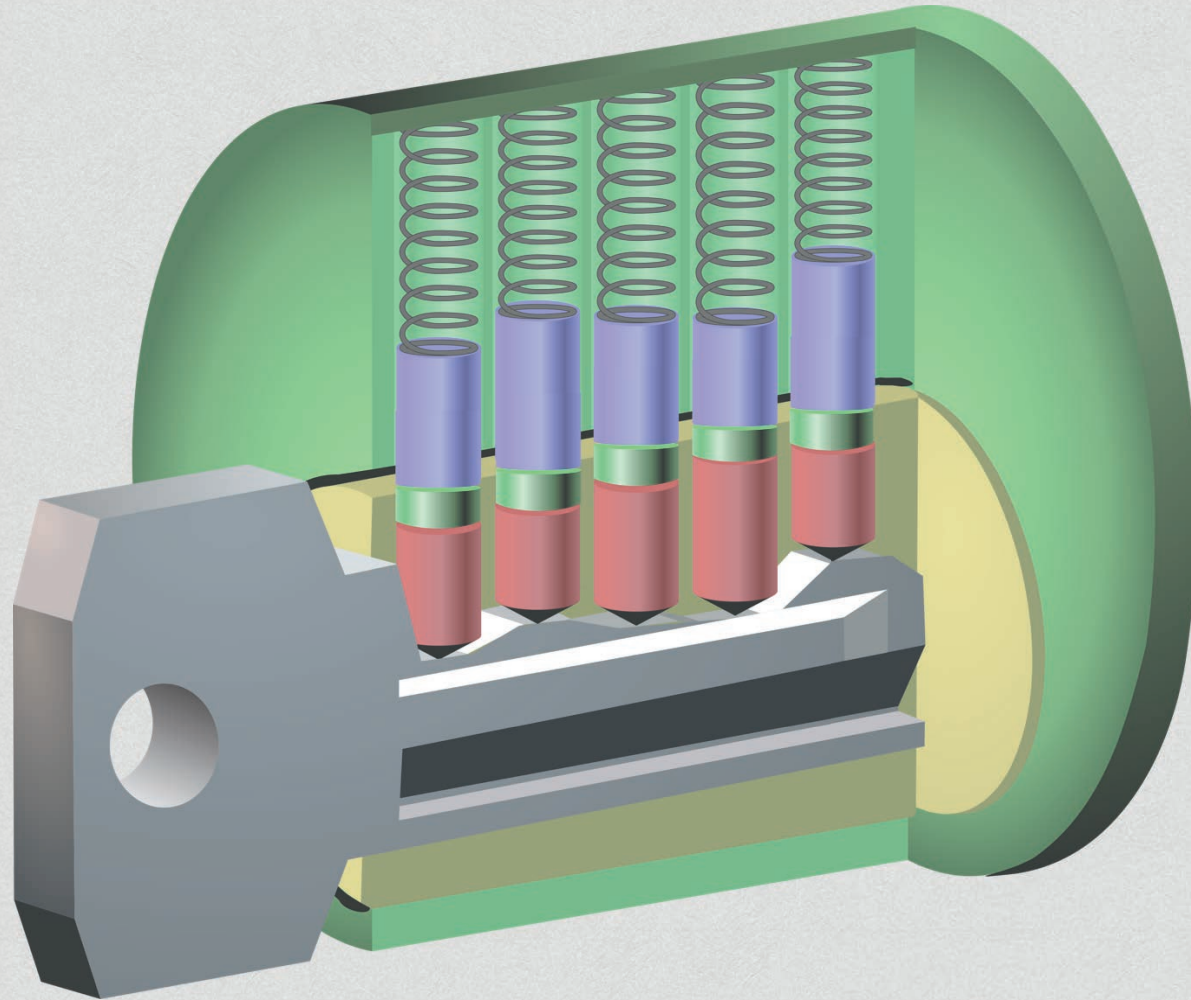
Change Key Inserted

Master Keyed Pin Tumbler Lock



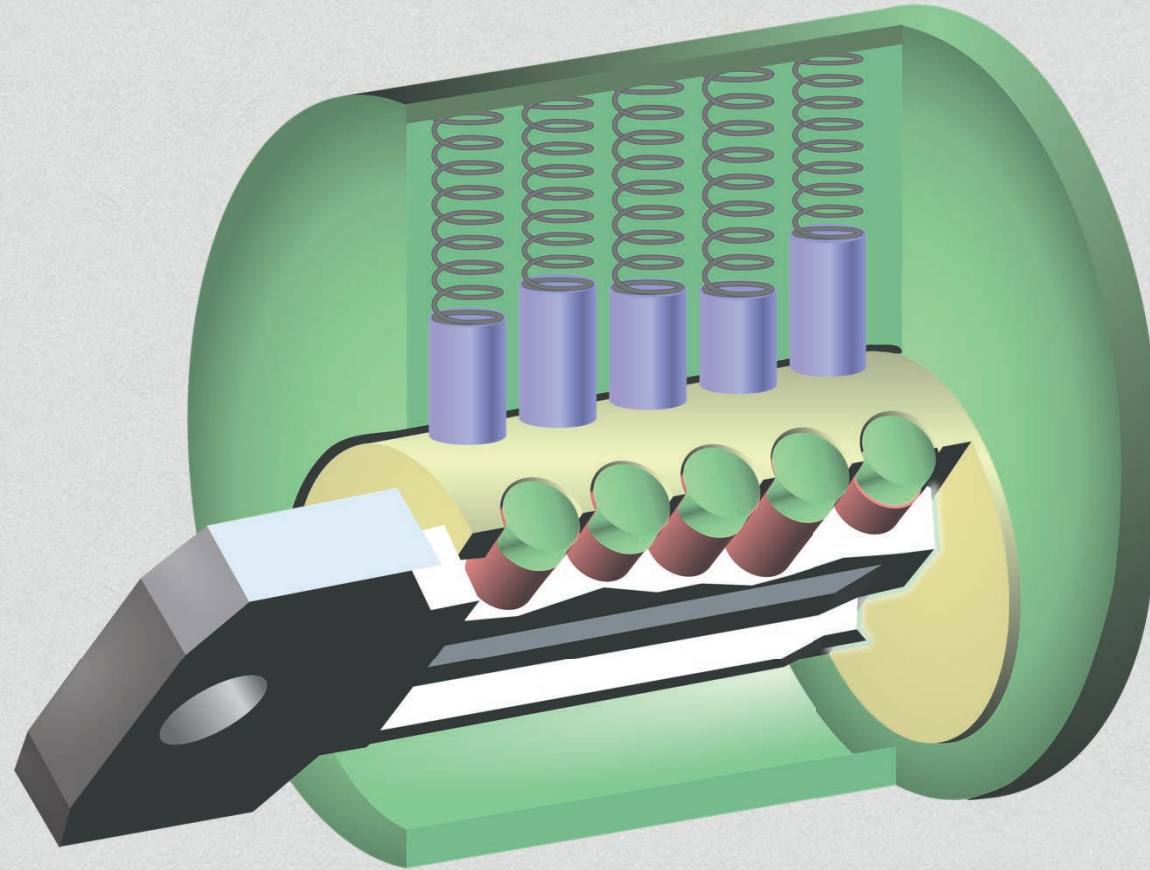
Change Key Inserted

Master Keyed Pin Tumbler Lock



Master Key Inserted

Master Keyed Pin Tumbler Lock

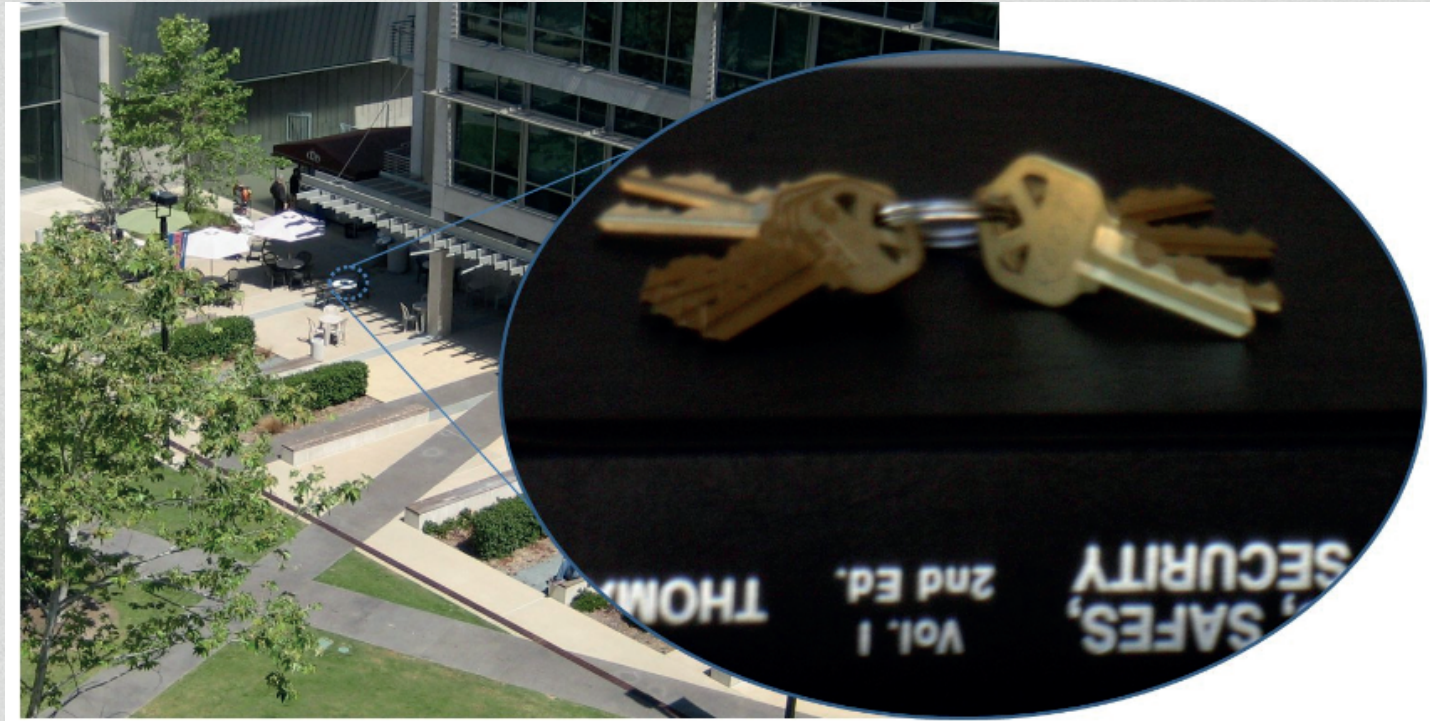


Master Key Inserted

- **Background**
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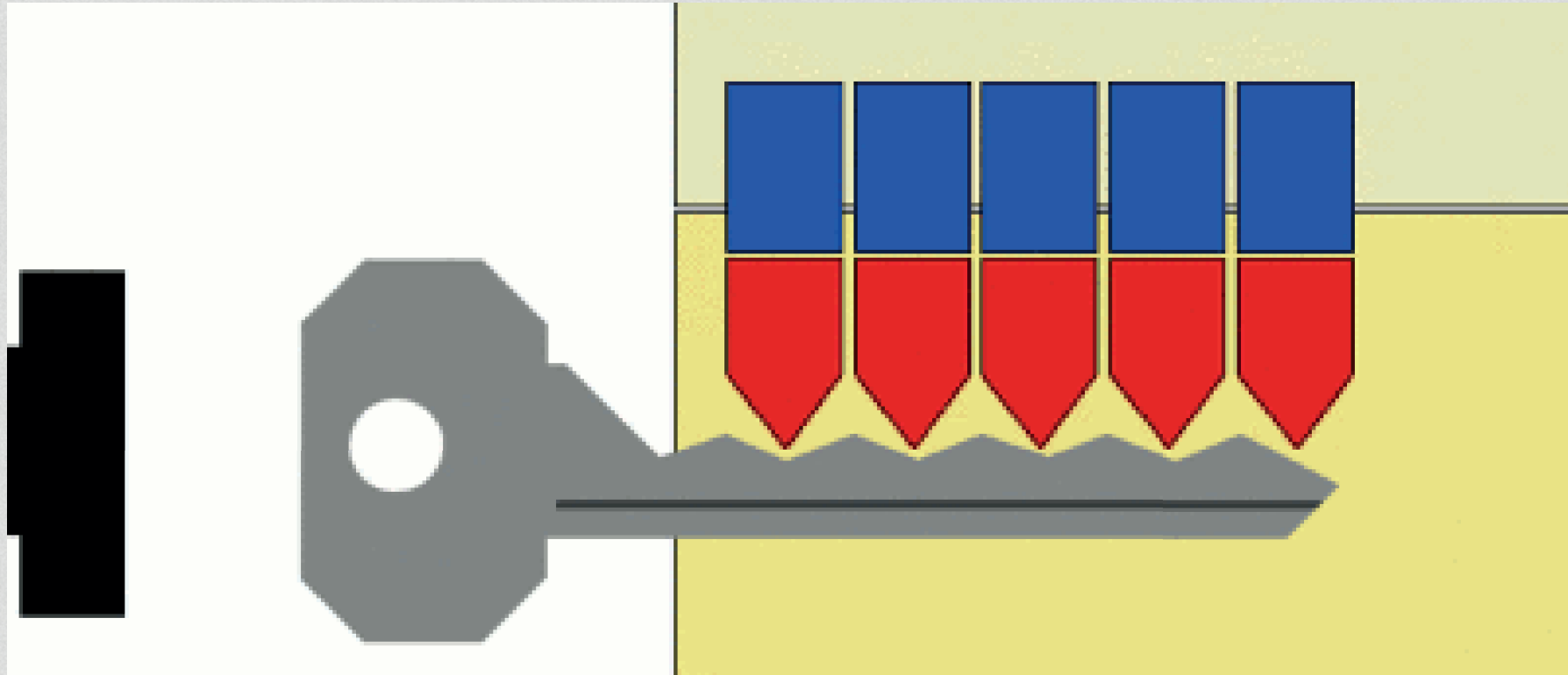
Teleduplication Attack

- Introduced in 2008 by Benjamin Laxton, Kai Wang, and Stefan Savage



Requires key blank

Bump Keys

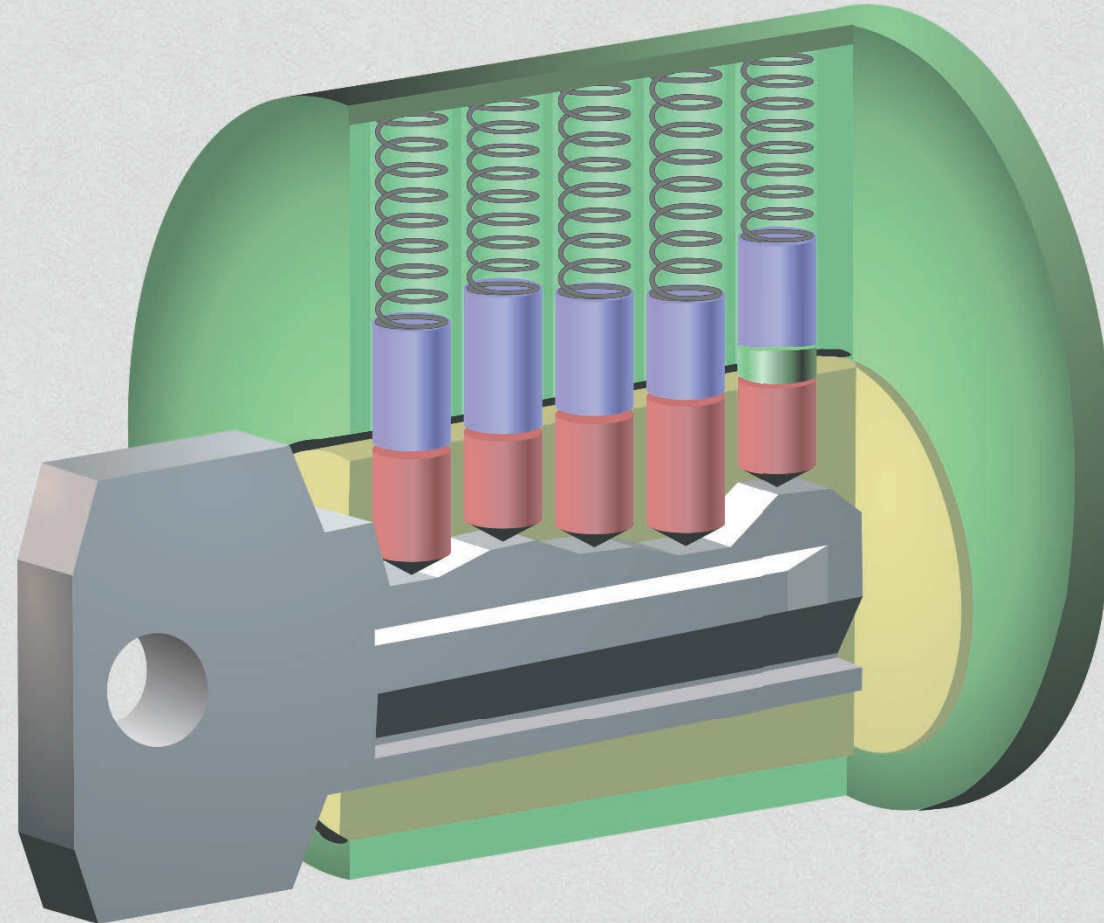


Requires key blank

Privilege Escalation Attack

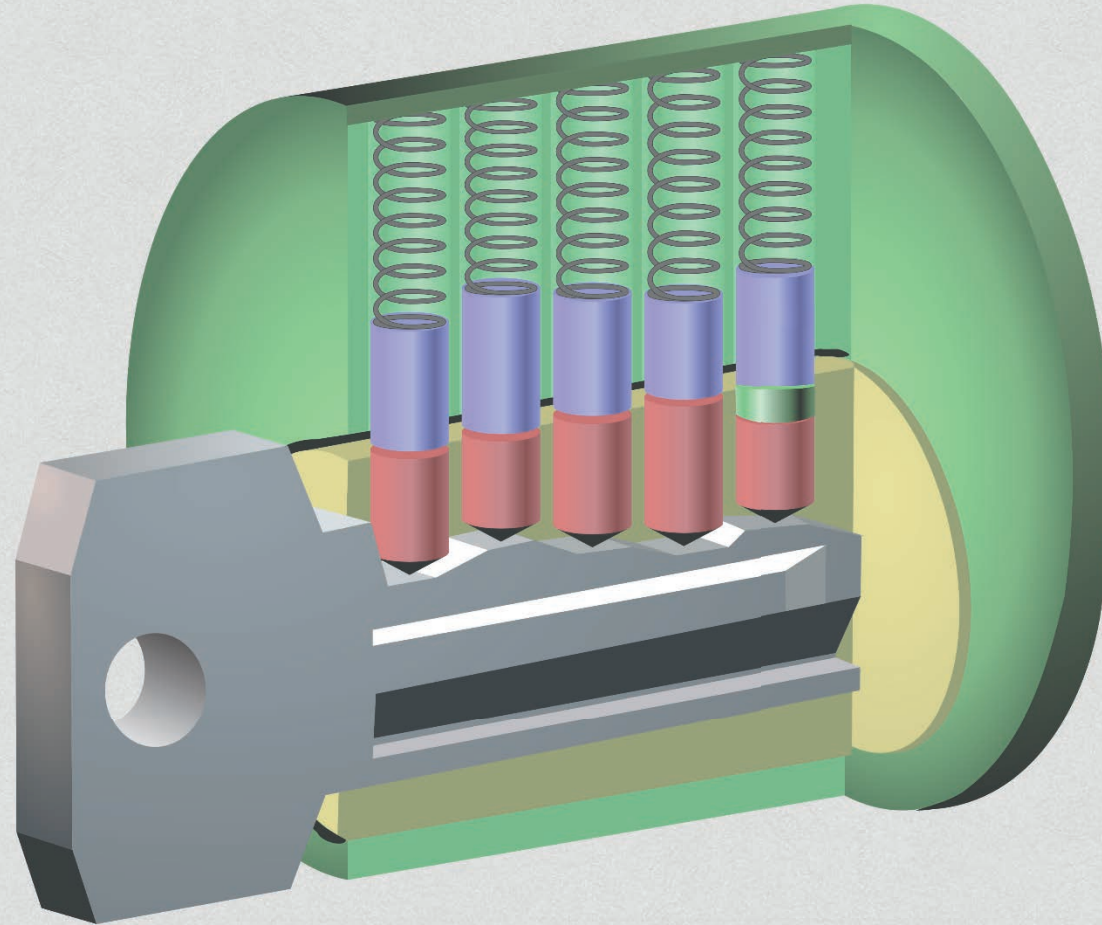
- Introduced in 2002 by Matt Blaze
- Only effective against master keyed locks
- Requires key blanks and a way to cut the key blanks
- Elevates a low level key that can open a single door to a key that can open every door in the system

Privilege Escalation Attack



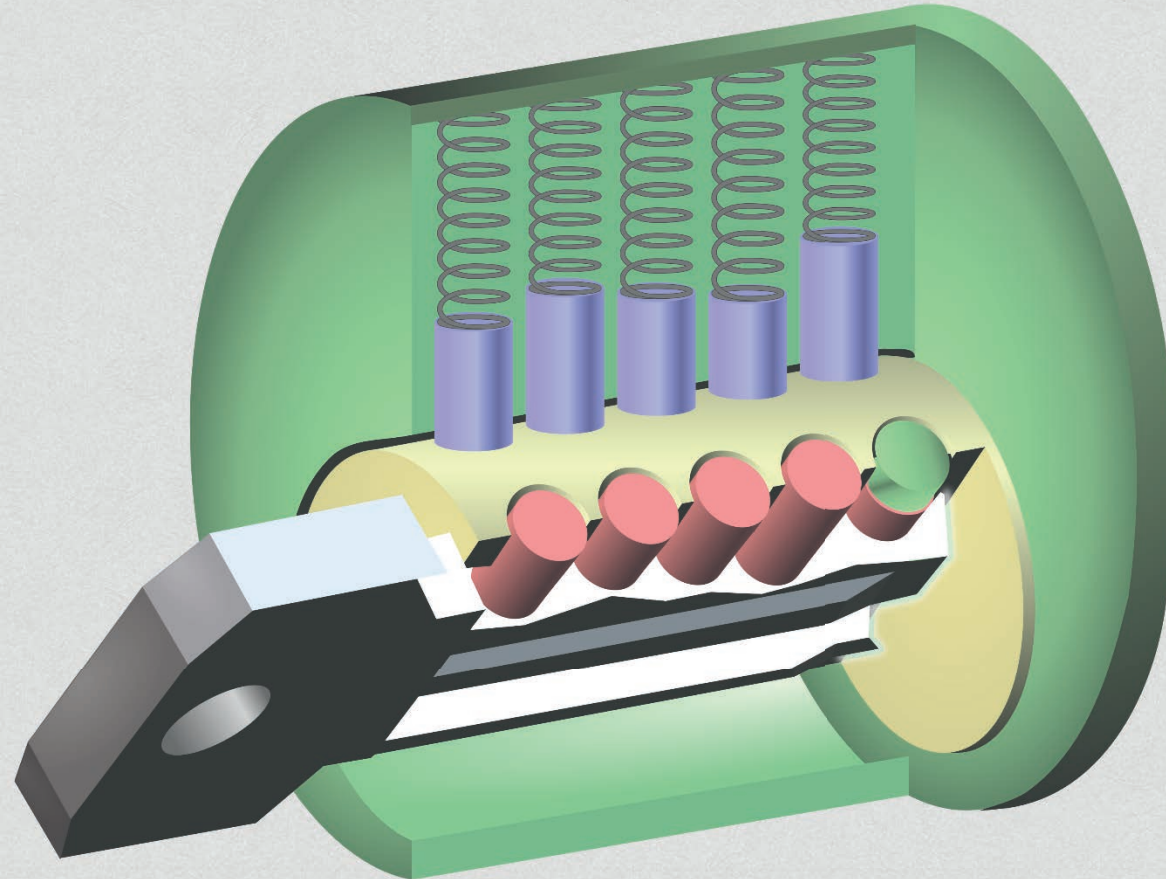
Change Key Inserted

Privilege Escalation Attack



Key Cut Down

Privilege Escalation Attack



Lock Unlocked

Requires key blank

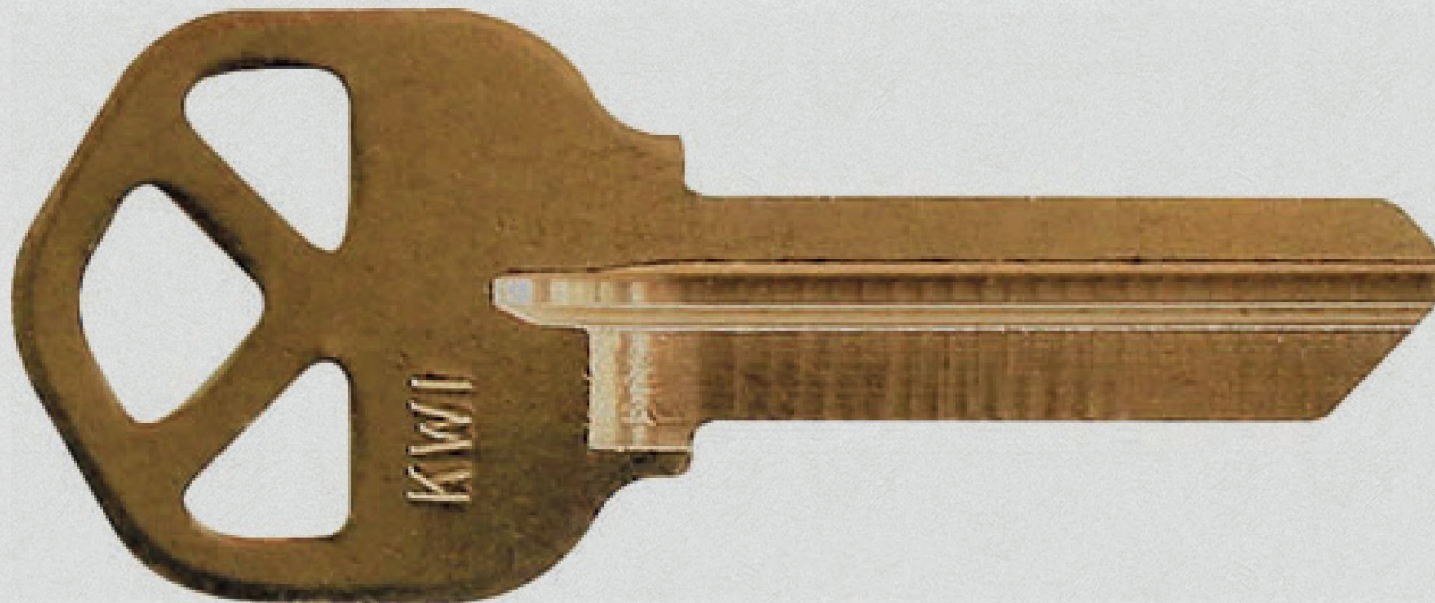
What do these attacks all have in common?

They all require key blanks

- **Background**
 - Basic Pin Tumbler Locks
 - Master Keying
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 - **Levels of Key Systems**
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Open Key Systems

- Keys can be easily copied at hardware stores
- Key blanks readily available online



Duplication Prohibited

- Keys stamped with duplication prohibited should not be copied by reputable locksmiths
- Key blanks still readily available online



Restricted Key Systems

- Key blank profile patented
- Key blanks can only be obtained from the manufacturer with proper proof of purchase of the system



Resistance to Aforementioned Attacks

Key System	Resistance
Open	None
Duplication Prohibited	Minimal
Restricted	High

Restricted key systems make obtaining
key blanks harder for attackers

- Background
- **3D Printing Keys**
 - **Previous Work**
 - Durability Testing
 - Automatically Generating Models of Keys
- Countermeasures
- Summary

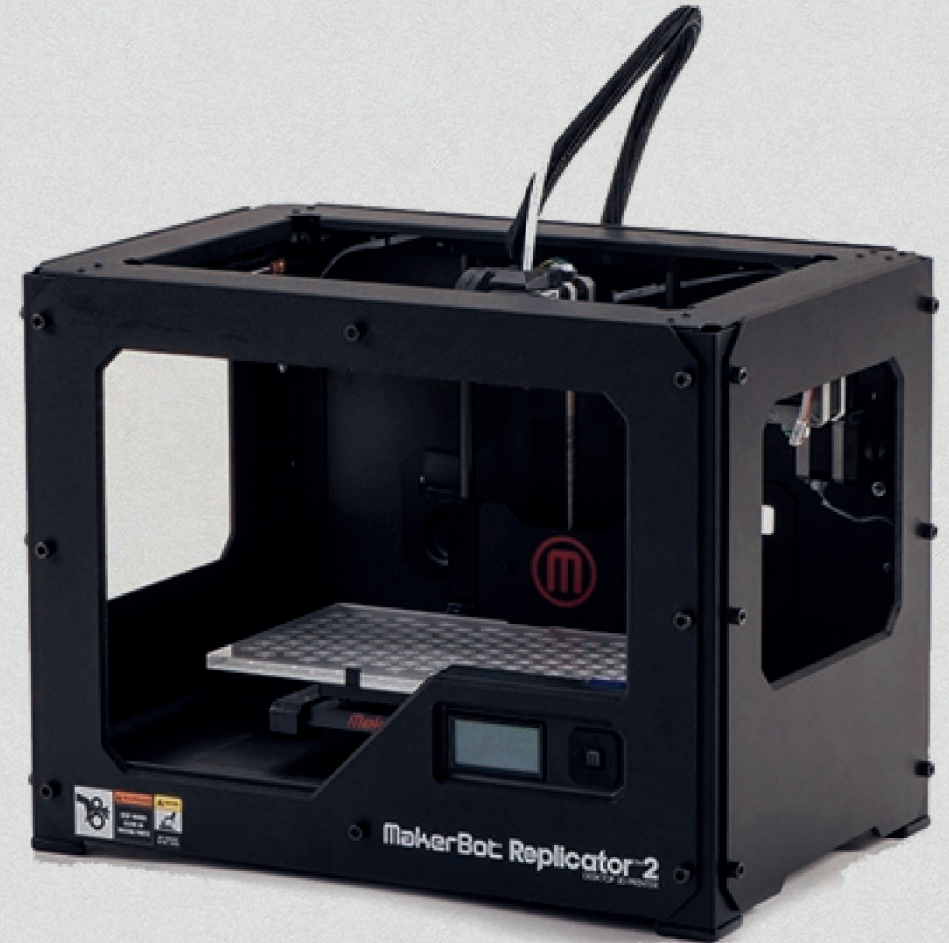
Traditionally Manufacturing Restricted Keys

- Expensive
- Difficult
- Limitations on reproduction of key features
- Resulting keys very durable



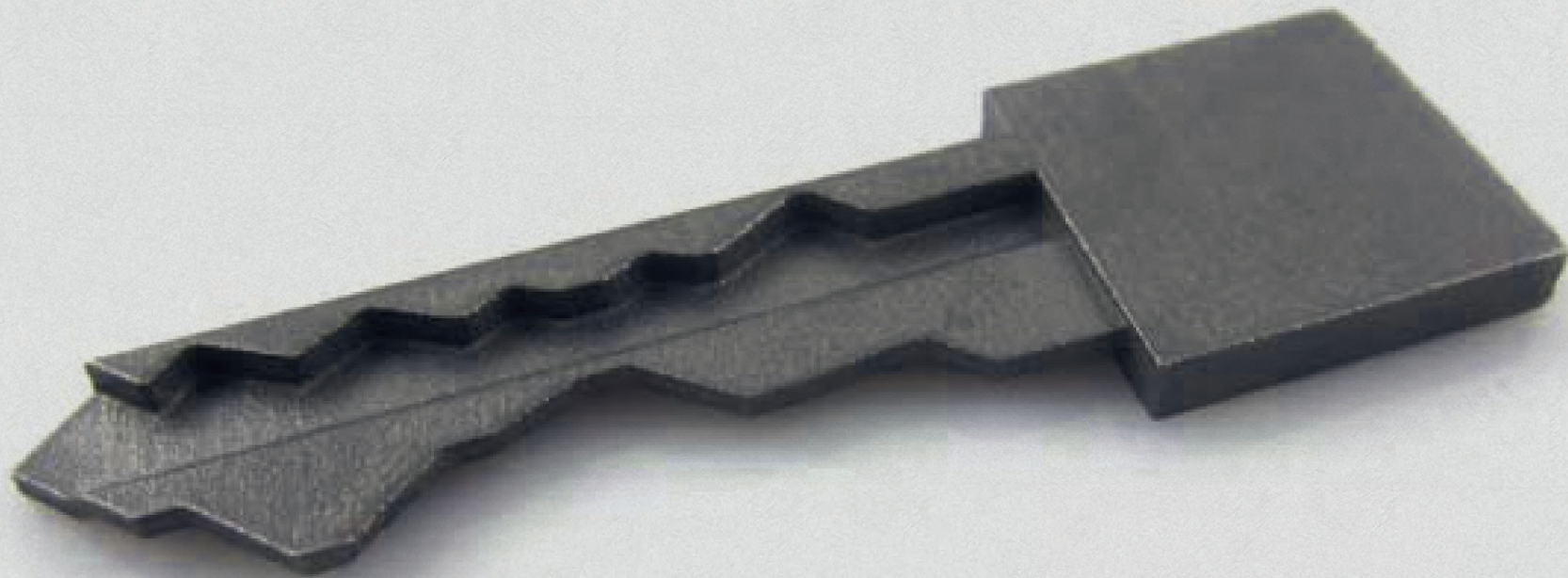
Benefits to 3D Printing

- Cheap
- Quick to produce with desktop 3D printer
- Capable of reproducing intricate key features



Schlage Primus

- Replicated using 3D printing by MIT students David Lawrence and Eric Van Albert in 2013



i.materialise does not support 3D printing high security keys

By Tatiana | August 6, 2013 | News | 5 Comments

At the Def Con hackers conference this past weekend MIT students David Lawrence and Eric Van Albert presented their [software tool](#) to allow people to 3D print high security keys. We were disappointed to see that our services were used by the students to make an unauthorized copy of a Schlage Primus key in titanium. i.materialise rejects any use of its services to promote activities or to create products which pose a safety or security risk to others. Had the intentions of David Lawrence and Eric Van Albert been known to i.materialise, the key would not have been printed.

Materials » Titanium

Material overview

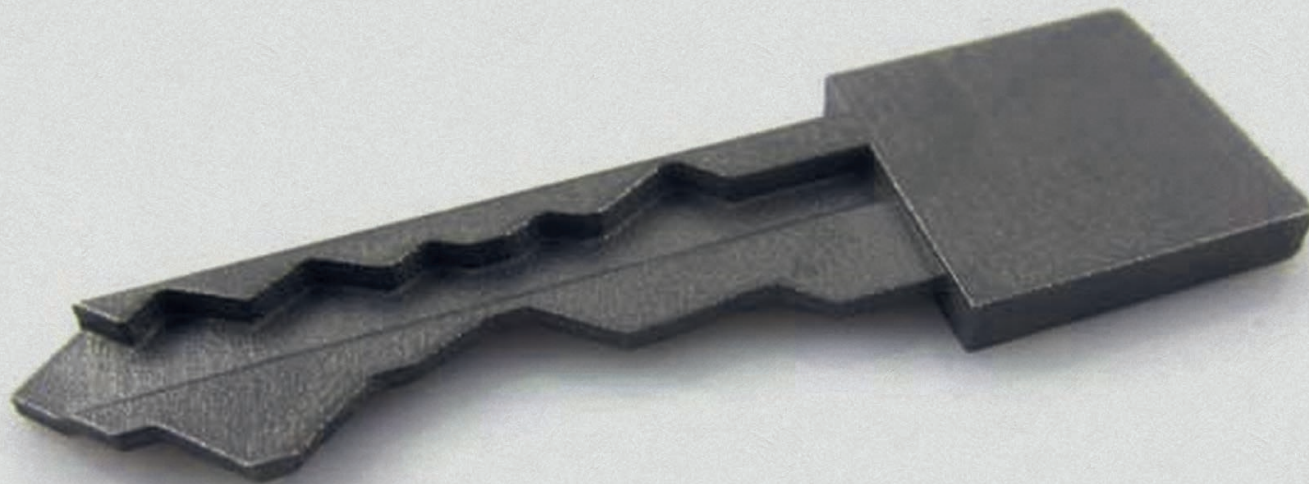
Colors and finishes

Design guide

Technical specifications

Unpolished

3D printed titanium (*unpolished*) doesn't look like the traditional shiny milled titanium. Instead it's a bit grayer and more matte with a slightly rougher and less defined surface.



But would the keys be durable
enough?

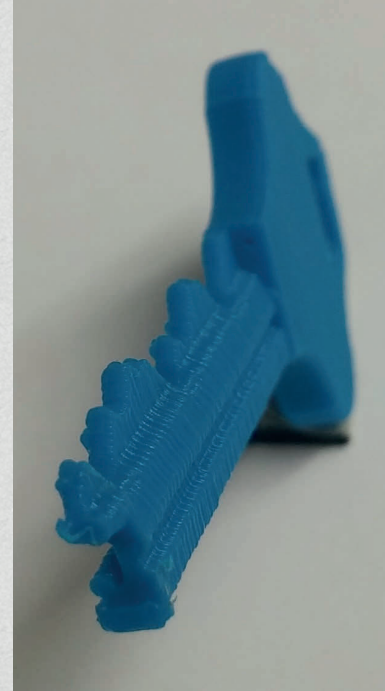
Let's print some keys and test!

- Background
- **3D Printing Keys**
 - Previous Work
 - **Durability Testing**
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Testing Methodology

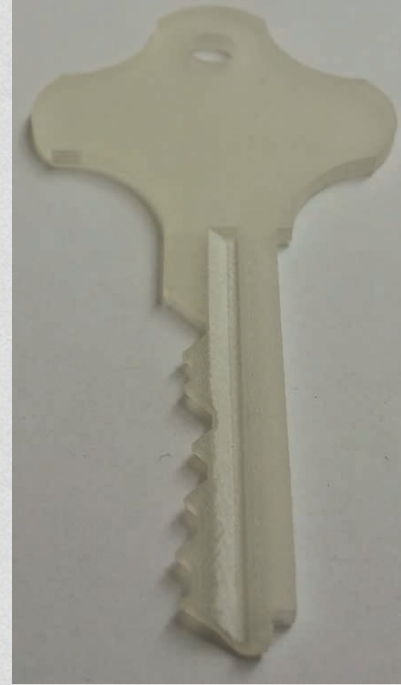
- **Opening force in common locks**
 - Determine the torque required to open the following locks:
 - Von Duprin Crash Bar
 - Various Padlocks
 - Schlage Office Door Lock
- **Breaking strength of 3D printed keys**
 - Place keys in locks they do not open and apply torque until the keys seriously deform or break

MakerBot PLA



	PLA
Cost	\$0.08
Door Latch	Pass
Door Unlock	Pass
Various Padlocks	Pass
Crash Bar	May Fail

Nylon



Acrylic

	PLA	Nylon - Acrylic
Cost	\$0.08	\$2.55 - \$8.28
Door Latch	Pass	May Fail
Door Unlock	Pass	Fail
Various Padlocks	Pass	Fail
Crash Bar	May Fail	Fail

Alumide



	PLA	Nylon - Acrylic	Alumide
Cost	\$0.08	\$2.55 - \$8.28	\$3.08
Door Latch	Pass	May Fail	Pass
Door Unlock	Pass	Fail	Pass
Various Padlocks	Pass	Fail	Fail
Crash Bar	May Fail	Fail	Fail

Plastic 3D Printed Keys

- Durable enough to use in attacks
- Quick to produce
- Cheap
- Not quite durable enough to use long term

What about metal 3D printing for more durable keys?

Metal 3D Printing

- Cheaper than CNC
- Generally lost wax cast modelling
- Increased durability when compared to plastic
- Capable of reproducing intricate key features

Materials Ordered from Service

- Stainless Steel
- Brass
- Bronze

Stainless
Steel



Brass

	PLA	Nylon - Acrylic	Alumide	Metal
Cost	\$0.08	\$2.55 - \$8.28	\$3.08	\$10.73 - \$25.03
Door Latch	Pass	May Fail	Pass	Pass
Door Unlock	Pass	Fail	Pass	Pass
Various Padlocks	Pass	Fail	Fail	Pass
Crash Bar	May Fail	Fail	Fail	Pass

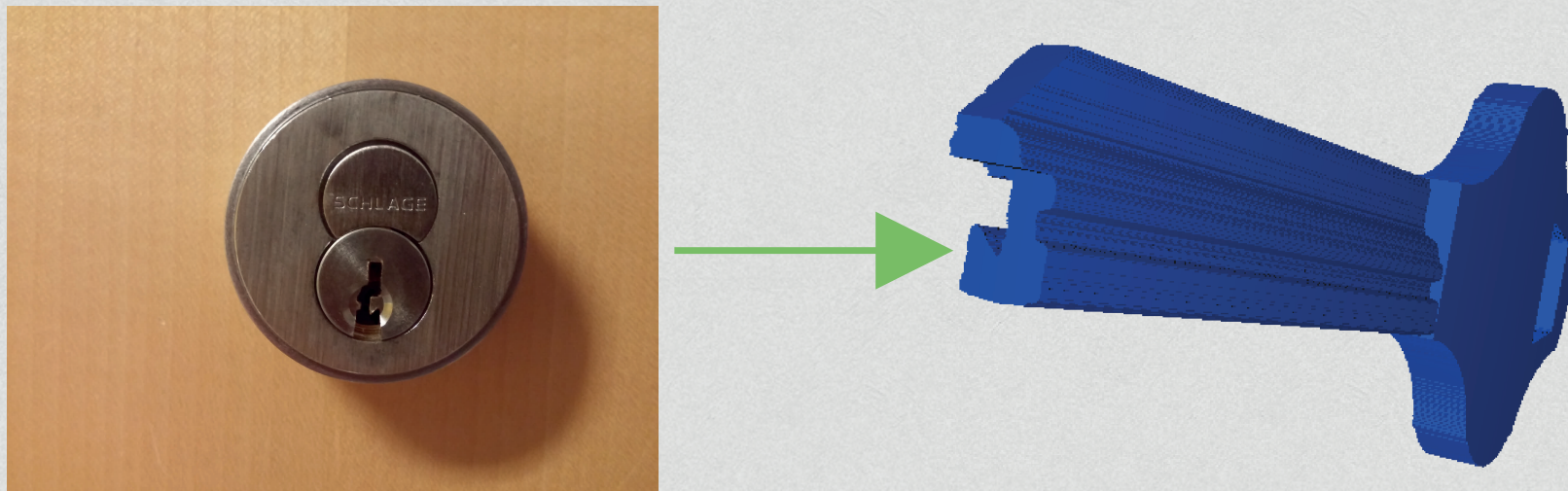
Attacks are still difficult since CAD knowledge is needed

```
XtoYscale = 0.325000000000;  
keyway_height = 0.320000000000;  
blade_width = keyway_height * XtoYscale;  
blade_length = 1.250000000000;  
translate([0, mm(keyway_height/2), 0])  
resize([mm(blade_width), mm(keyway_height) / (0.352764706), 0], auto=true)  
translate([-minx+dx/2, -miny+dy/2, 0]) rotate([0, 0, 180]) translate([-minx-dx/2, -miny-dy/  
2, 0])  
linear_extrude(height=1, convexity=362)  
union() { translate([0, 0, .5]) resize([1, 1, 1,]) rotate([90, 0, 90]) difference()  
  { union() { scale([1,1,2]) translate([0,0, 0]) bow(); }  
  translate([0,0,-2]) cube([2,2,4],center=true); }  
}
```

- Background
- **3D Printing Keys**
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Automatically Generating CAD Models

- Convert the image to black and white
- Find the keyway in the image
- Convert the cross section of the keyway into a 3D model



B&W Conversion Techniques

- Canny Edge Detection
- Circle Hough Transform
- **Thresholding**

Thresholding

A certain intensity between
0 and 255 is chosen

Everything above that value is white
while everything below is black

Test Image



Smartphone Picture of Lock

Image at Different Threshold Points



25



35 (Optimal)



45

Blob Detection

The keyway looks to be the largest blob of black pixels in an image

Largest Blobs



25



35 (Optimal)



45

Can the threshold point be determined automatically?

What if we analyzed the area of the output blobs

Largest Blobs



25

0.005



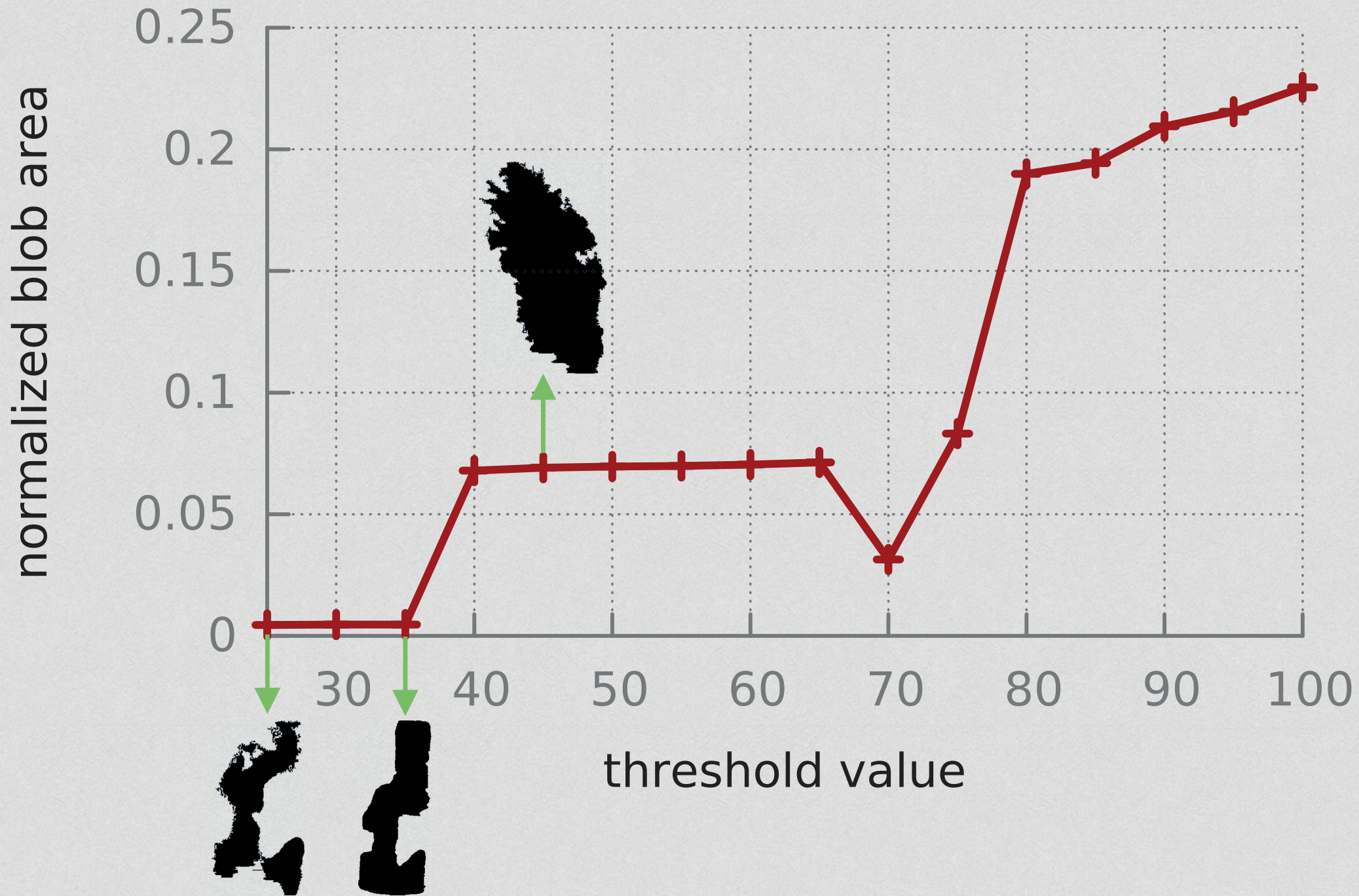
35 (Optimal)

0.005



45

0.075



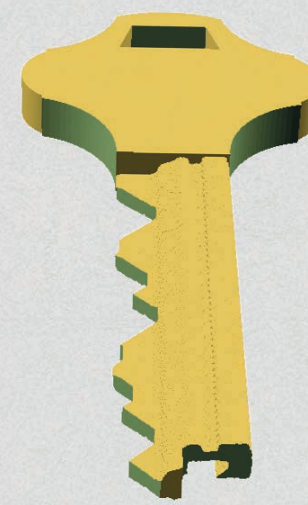
Keyway Mask



CAD Generation

With the cross section of the keyway
extruding a key in OpenSCAD is trivial

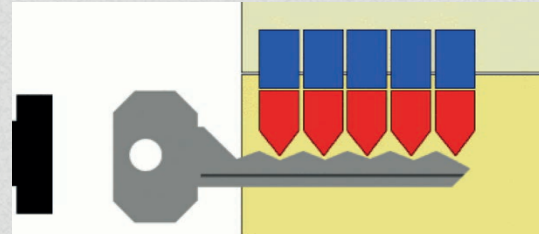
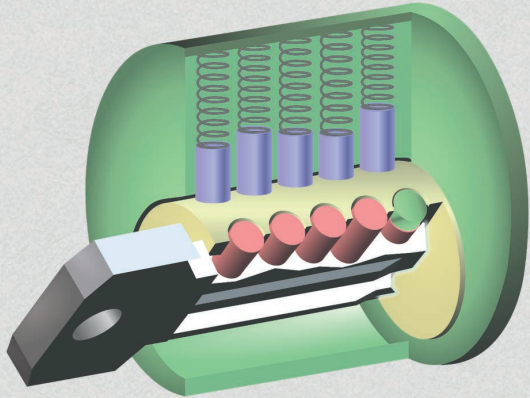
Input Image



```
blade_create([9, 1, 7, 9, 2, 4, 8]);
```

Let's revisit the protection restricted
key systems provide now that we
know durable keys can be 3D printed

Attacks Enabled by 3D Printing

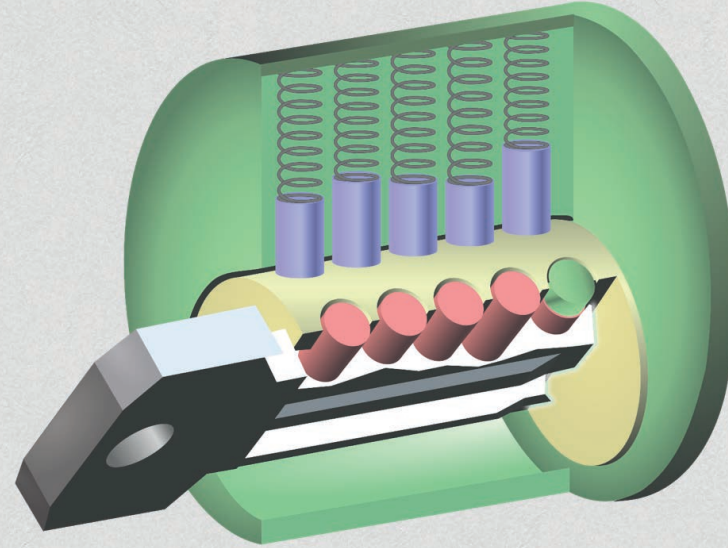


Privilege Escalation

Bump Keys

Teleduplication

Privilege Escalation Attack Cost



5 Plastic Keys (\$0.08)

1 Metal Key (\$10.73)

\$11.13

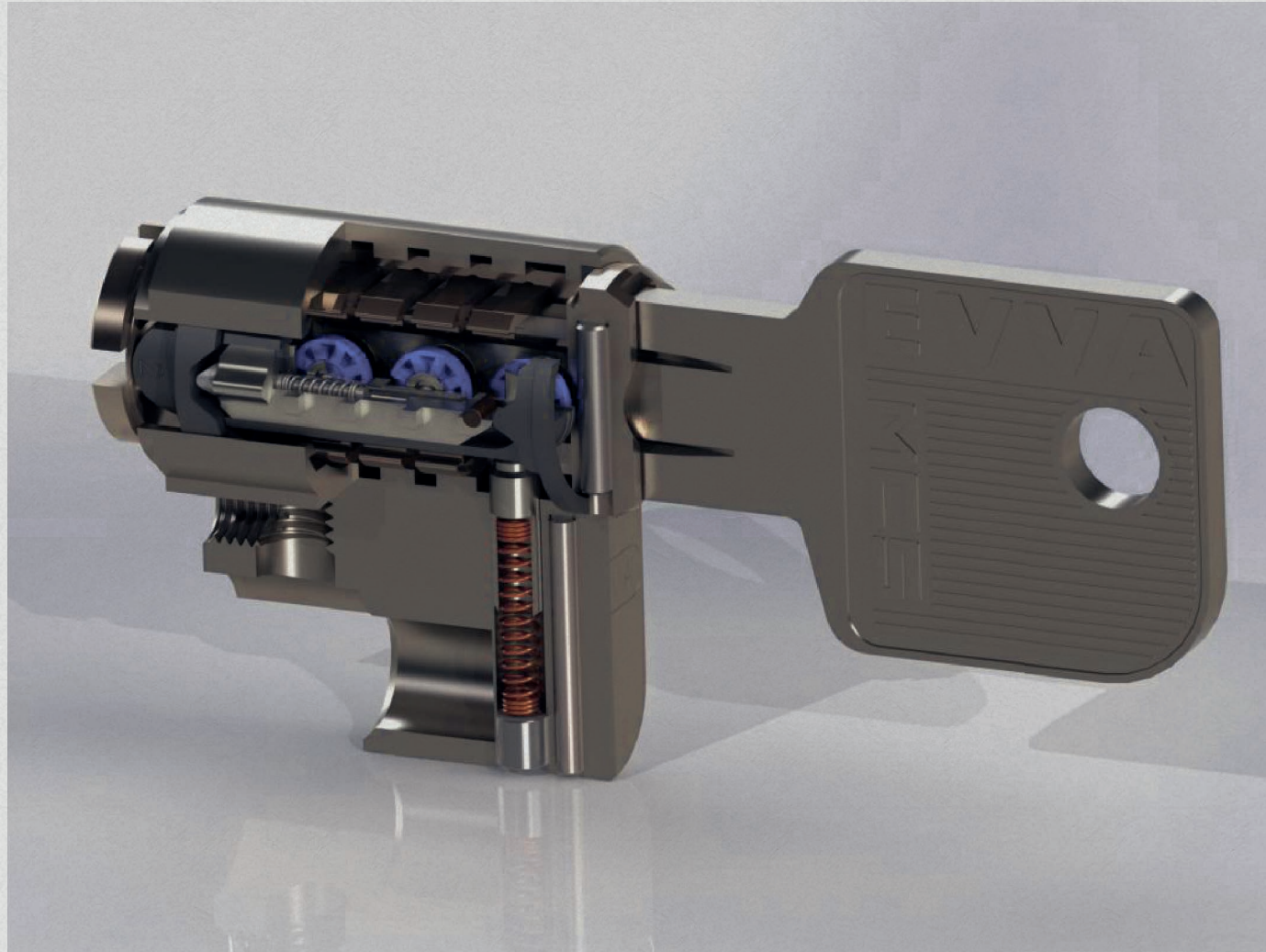
- Background
- 3D Printing Keys
- **Countermeasures**
 - **Non-mechanical Locks**
 - Active Keyways
 - Trap Keyways
 - Cost
- Summary

Non-mechanical locks

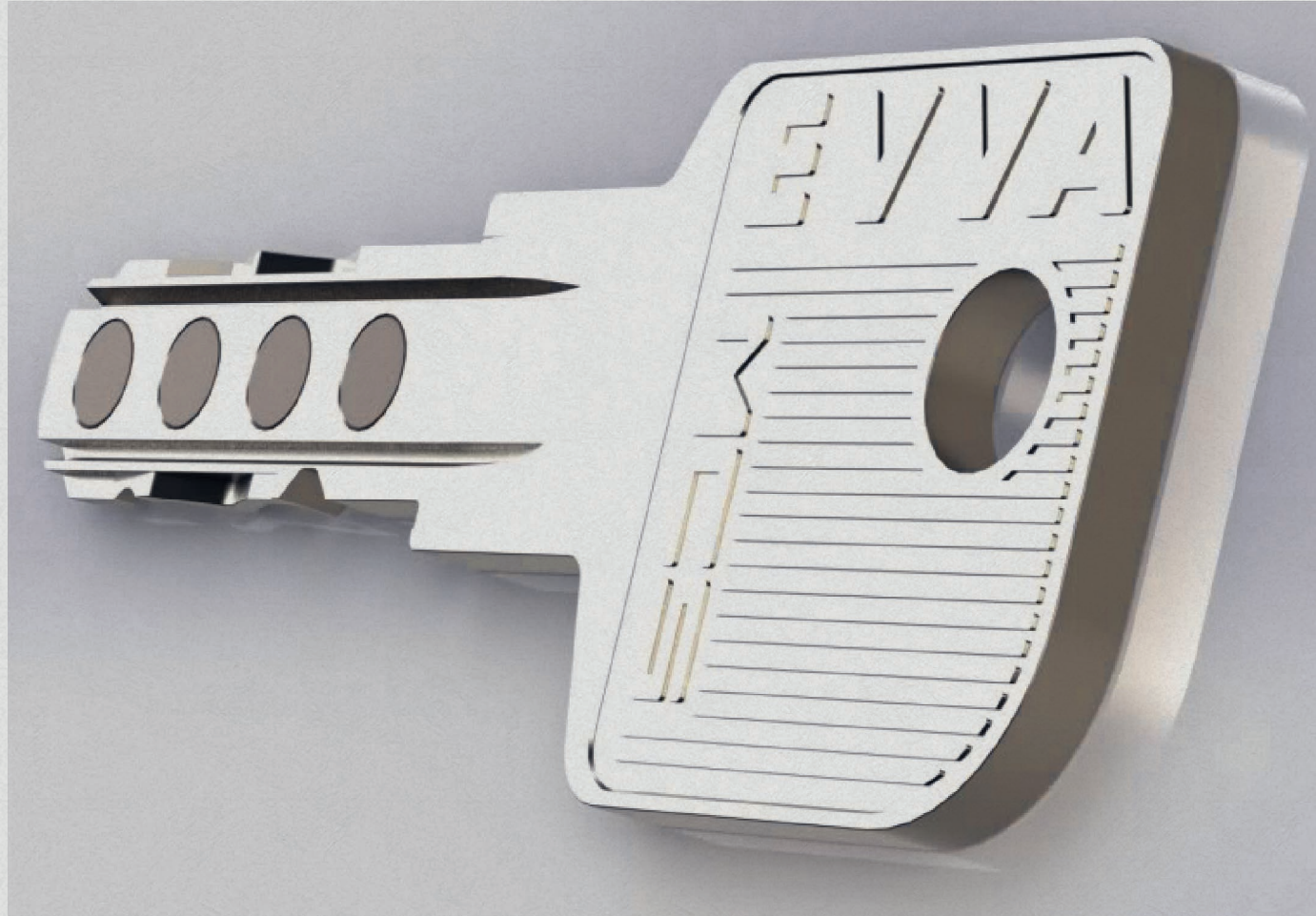


- Background
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- **Countermeasures**
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Active Keyways



Active Keyways



- Background
- 3D Printing Keys
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 - **Trap Keyways**
 - Cost
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Trap Keyways

- Can be configured to trap a certain cut on each pin stack
- Could be used to prevent privilege escalation attacks
- Once a key has been trapped the lock must be destroyed to remove it

- Background
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Lock	Cost
Standard Restricted Keyway	\$50
Non-mechanical	\$300-500
Active Keyways	\$200-500
Trap Keyways	Not Available

- Background
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- Countermeasures
- **Summary**

Summary

- 3D keys are durable enough to use in attacks
- 3D models of keys can be easily generated
- Restricted keyways should not be the sole line of defense against the aforementioned attacks

Automated tool available for testing at:

<https://keysforge.com>

https://keyforge.com/

keyforge

[About](#)

[Demo](#)

[Code](#)

[Paper](#)

Keyway Picture

No file chosen

Key Cuts (optional)

000000

https://keysforge.com/

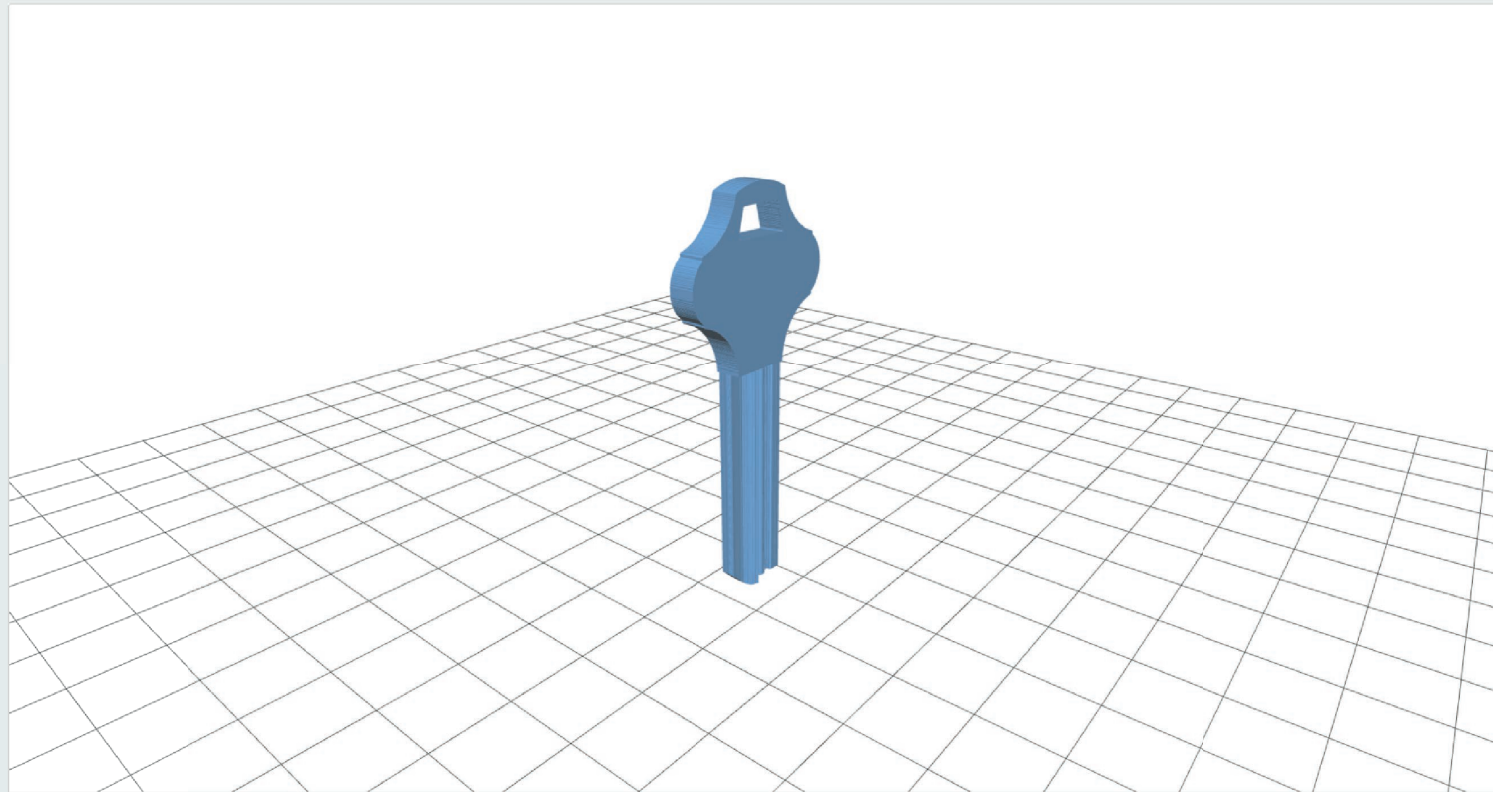
keysforge

About

Demo

Code

Paper



Wireframe | Surface Angle | **Solid**

rendered with ❤️ by GitHub

Download STL

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<https://keysforge.com>

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