



A Peek into the Metaverse: Detecting 3D Model Clones in Mobile Games

Chaoshun Zuo, Chao Wang, and Zhiqiang Lin

USENIX Security 2023

Prosperity of Metaverse



* Demonstration is credit to <https://www.searchenginejournal.com/metaverse/484803/>

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TECH

Meta Acquires Berlin Startup to Boost Virtual-Reality Ambitions

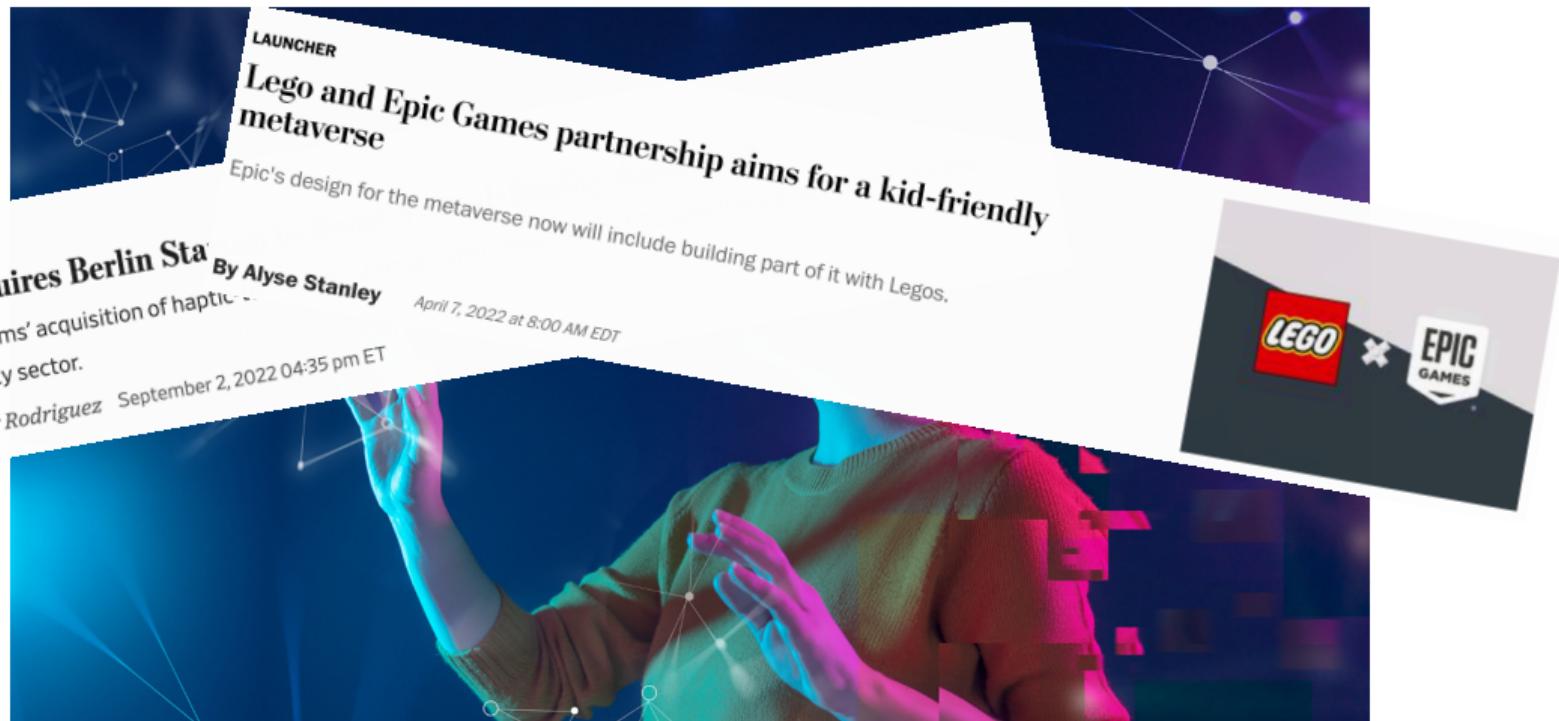
Meta Platforms' acquisition of haptic-technology startup Lofelt comes as the FTC says it is trying to dominate the virtual-reality sector.

By Salvador Rodriguez September 2, 2022 04:35 pm ET



* Demonstration is credit to <https://www.searchenginejournal.com/metaverse/484803/>

Prosperity of Metaverse



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Prosperity of Metaverse

TECH

Meta Acquires Berlin Sta^{By Alyse Stanley}

Meta Platforms' acquisition of haptic virtual-reality sector.

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LAUNCHER

Lego and Epic Games partnership aims for a kid-friendly

Epic's design for the metaverse now will include building part of it with Legos.

April 7, 2022 at 8:00 AM EDT

BUSINESS

Apple Is Breaking Its Own Rules With a New Headset

Apple's soon-to-be-revealed mixed-reality device will likely cost \$3,000, requires a separate battery pack and is still experimental.

By Aaron Tilley and Yang Jie May 12, 2023 09:00 am ET

Appeared in the May 13, 2023, print edition as 'Apple Is Breaking Its Own Rules With a New Headset'

... is credit to <https://www.searchenginejournal.com/metaverse/484803/>

Prosperity of Metaverse

TECH

Met Gala Acquires Berlin Startup By Alyse Stanley
WIRECUTTER

April 7, 2022 at 8:00 AM EDT
- am ET

Apple's Vision Pro AR/VR Headset: Bold, Innovative, and Ridiculously Expensive
By Aaron Tilley and Yang Liu
Apparated in the May 13, 2023, print edition
augmented reality headset called the Apple Vision Pro.

experience...
By Aaron Tilley and Yang Liu
Appeared in the May 13, 2023, print edition
... is credit to <https://www.searchenginejournal.com/metaverse/484803/>

LAUNCHER
Lego and Epic Games partnership aims for a kid-friendly metaverse
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... separate battery pack and is still

Prosperity of Metaverse



LAUNCHER
Lego and Epic Games partnership aims for a [Lego Metaverse](#)
Epic's design focus



REAL ESTATE

TECH
Met
vir
By

The Next Hot Housing Market Is Out of This World. It's in the Metaverse.

Despite the implosion of FTX and projections of a cryptocurrency winter, the metaverse real estate market is expected to grow by \$5.37 billion by 2026.

By Debra Kamen

Used the Apple Vision Pro.

experience...
By Aaron Tilley and Yang...
Appeared in the May 13, 2023, print edition...
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3D models are vital for 3D games

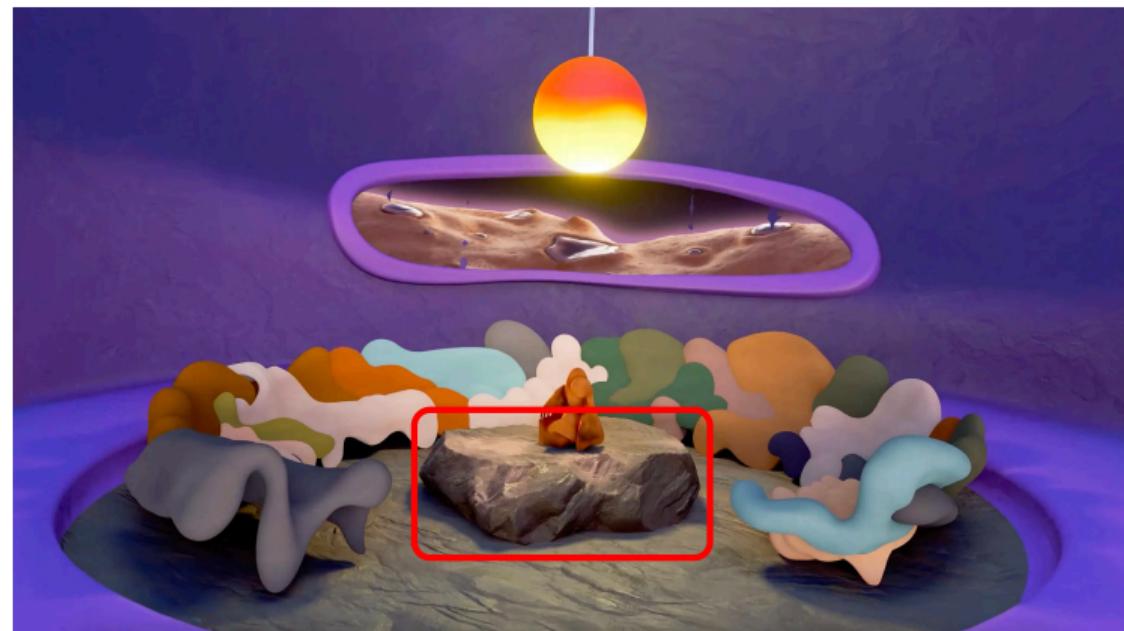


An immersive scene of a 3D game

3D models are vital for 3D games

It has ...

① Table



An immersive scene of a 3D game

3D models are vital for 3D games

It has ...

- ① Table
- ② Figure

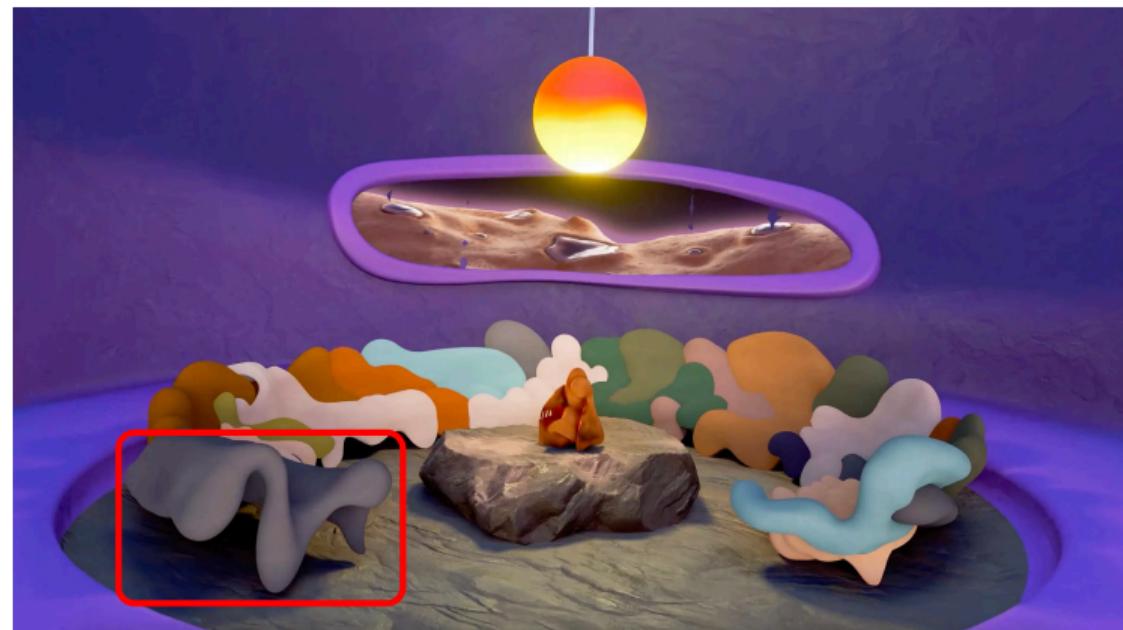


An immersive scene of a 3D game

3D models are vital for 3D games

It has ...

- ① Table
- ② Figure
- ③ Chair

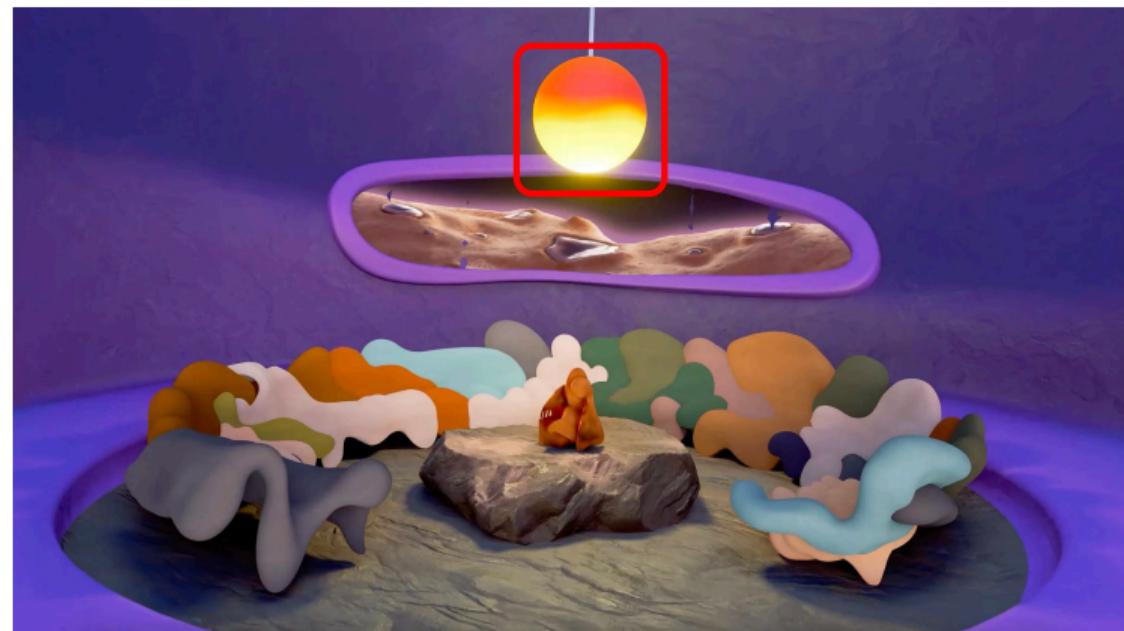


An immersive scene of a 3D game

3D models are vital for 3D games

It has ...

- ① Table
- ② Figure
- ③ Chair
- ④ Light



An immersive scene of a 3D game

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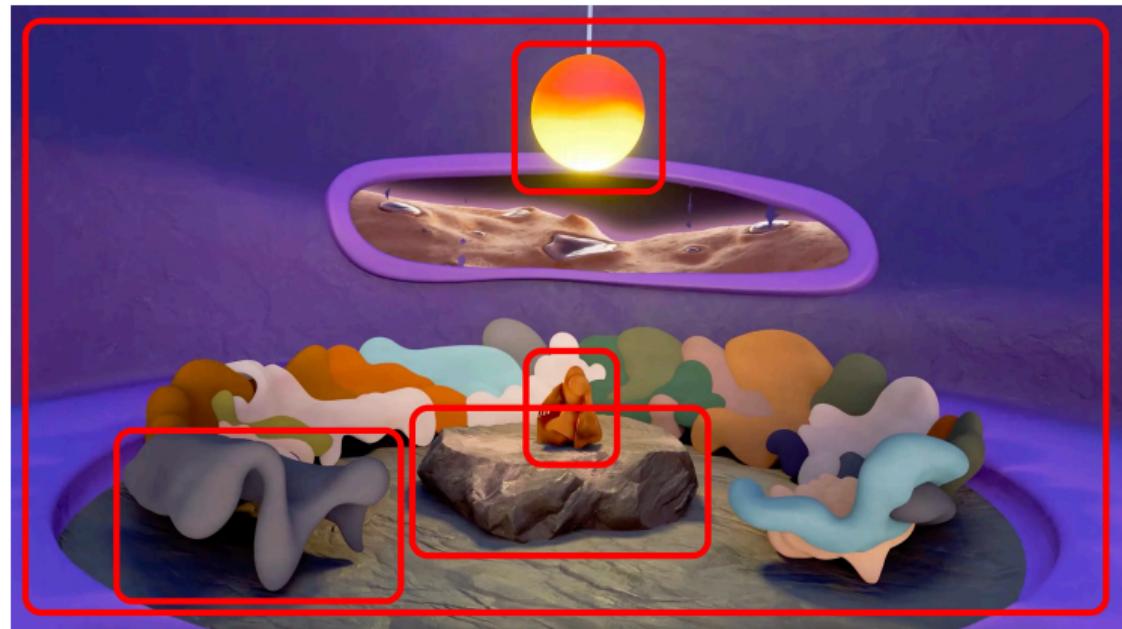
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- ① Table
- ② Figure
- ③ Chair
- ④ Light
- ⑤ Scene
- ⑥ ...

All of them are 3D
models!



An immersive scene of a 3D game

It's hard and costly to create 3D models

The art The 3D Model



It's hard and costly to create 3D models

The art



The 3D Model



It's hard and costly to create 3D models



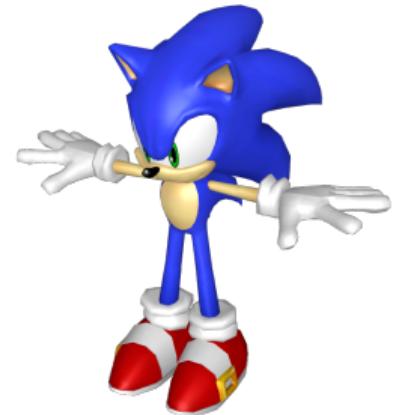
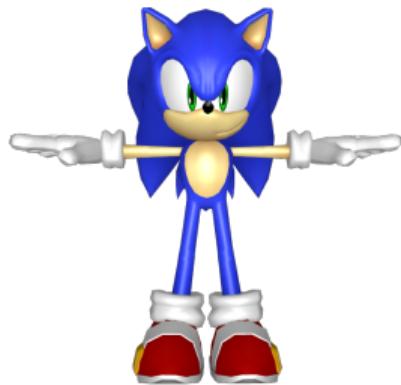
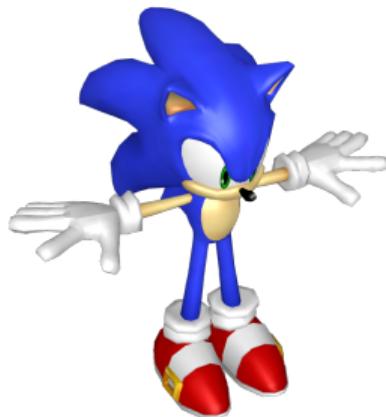
- ▶ **Size:** 714MB
- ▶ **Vertices:** 945.8K+
- ▶ **Triangles:** 1.9M+

It's hard and costly to create 3D models



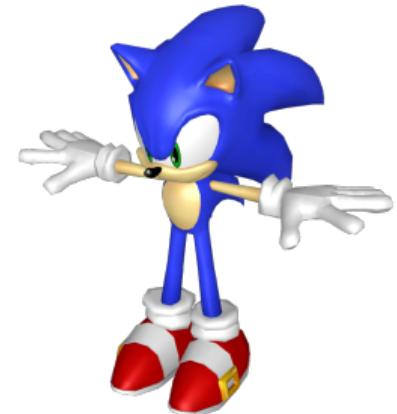
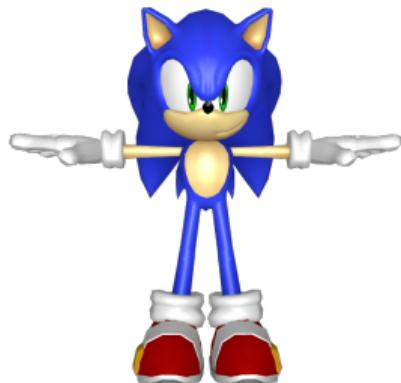
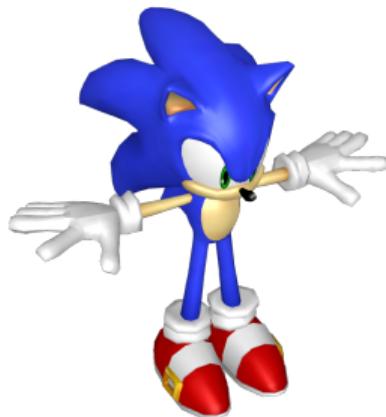
\$ 3,499 !

Then the 3D models should have been protected well?



Sonic the Hedgehog: Representative of SEGA

This is not true!



The 3D model shown above is extracted from their games!*

* Sonic the Hedgehog is an open-sourced model.

Protect 3D models

Multiple reasons that 3D models are currently not being protected properly...

Protect 3D models

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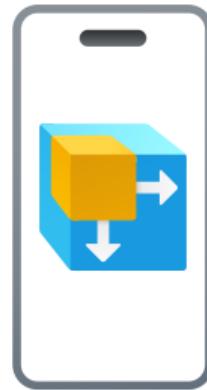
Distribute w/ games

Protect 3D models

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Distribute w/ games



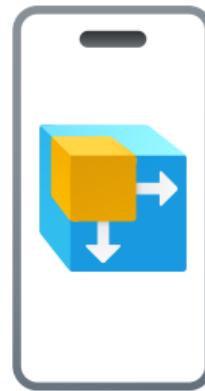
Render on client

Protect 3D models

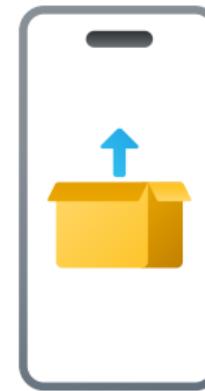
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Distribute w/ games



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Extract easily

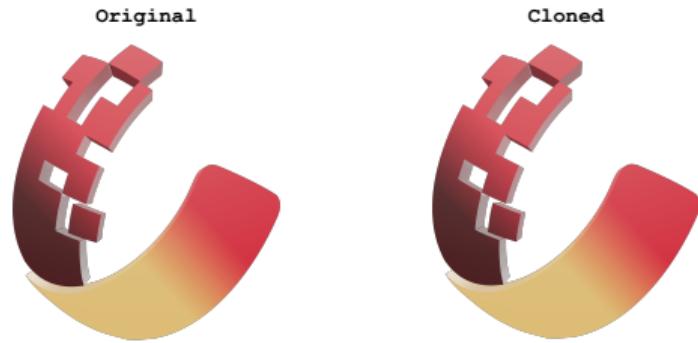
Real cases that 3D models get stolen

 General Discussions finding stolen models	Last post by 512pixel 30 days ago	213	7
 General Discussions Model Thief Collection	Last post by vis-all-3d about 1 month ago	2,092	60
 Selling / Buying 3D Models Stolen models	Last post by dustinmeyer1234 5 months ago	178	1
 Selling / Buying 3D Models Please Please use watermark on your images!!Request for all 3d print character artists!!	Last post by HP-DSignZ 5 months ago	272	13
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How to detect model stealing...



Detect models that look exactly the same?

(A)

```
g default
v 3.582481 4.277774 2.030798
v 3.539094 4.274003 2.030447
v 3.495418 4.270348 2.030093
v 3.451975 4.266842 2.029739
...
f 121 123 122
f 120 123 121
f 120 124 123
...
```

File Content

(B)

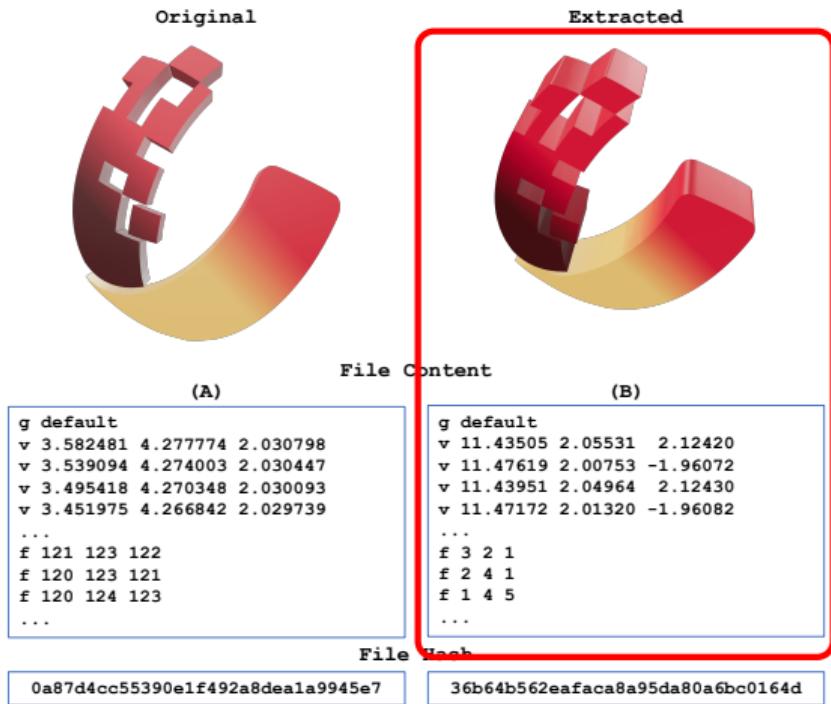
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v 3.495418 4.270348 2.030093
v 3.451975 4.266842 2.029739
...
f 121 123 122
f 120 123 121
f 120 124 123
...
```

File Hash

0a87d4cc55390e1f492a8dea1a9945e7

0a87d4cc55390e1f492a8dea1a9945e7

How to detect model stealing...



Detect models that look exactly the same?

Models can be ...

- ▶ Squashed
- ▶ Stretched
- ▶ ...

How to detect model stealing...

Original Extracted

(A)

```
g default
v 3.582481 4.277774 2.030798
v 3.539094 4.274003 2.030447
v 3.495418 4.270348 2.030093
v 3.451975 4.266842 2.029739
...
f 121 123 122
f 120 123 121
f 120 124 123
...
```

(B)

```
g default
v 11.43505 2.05531 2.12420
v 11.47619 2.00753 -1.96072
v 11.43951 2.04964 2.12430
v 11.47172 2.01320 -1.96082
...
f 3 2 1
f 2 4 1
f 1 4 5
...
```

File Hash

0a87d4cc55390e1f492a8dea1a9945e7 36b64b562eafaca8a95da80a6bc0164d

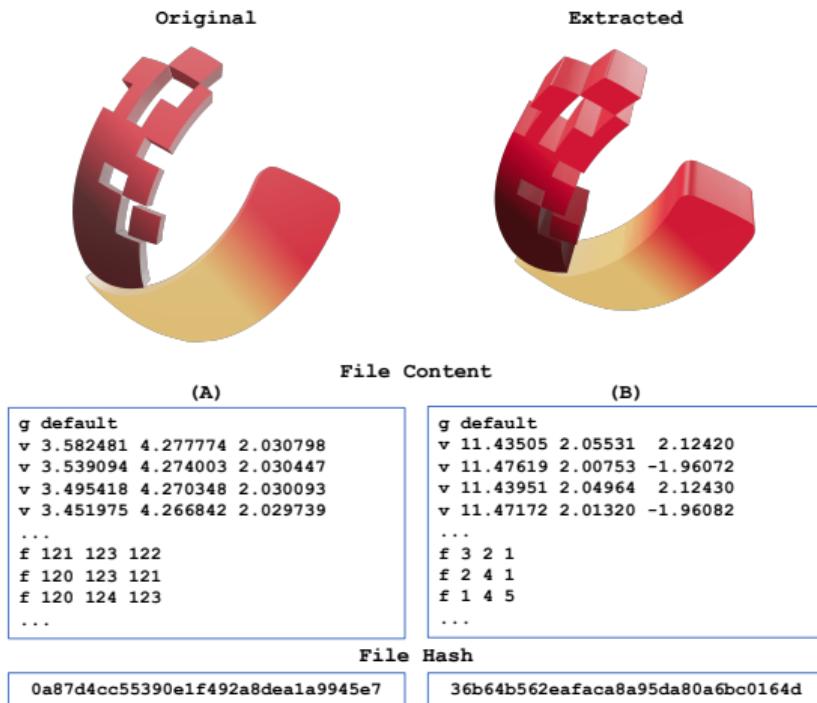
Detect models that look exactly the same?

Models can be ...

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- ▶ ...

The file hash will also be different!

How to detect model stealing...



Detect models that look exactly the same?

Models can be ...

- ▶ Squashed
- ▶ Stretched
- ▶ ...

The file hash will also be different!

How to design a robust and efficient 3D model indexing scheme?

What is demanded

Challenges

- ① Robust algorithm to handle the noise in static 3D models
- ② Robust algorithm to handle the noise in dynamic 3D models
- ③ Efficient algorithm to conduct large scale study

Our solutions

Solutions

- ① Robust algorithm to handle the noise in static 3D models
Model representing by relative values
- ② Robust algorithm to handle the noise in dynamic 3D models
Animation interpolation
- ③ Efficient algorithm to conduct large scale study
Index-based 3D model database

How does a 3D model look like



g usenix

How does a 3D model look like



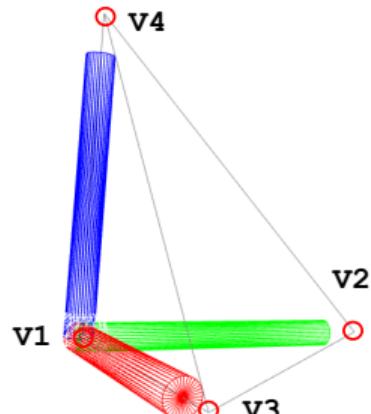
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...
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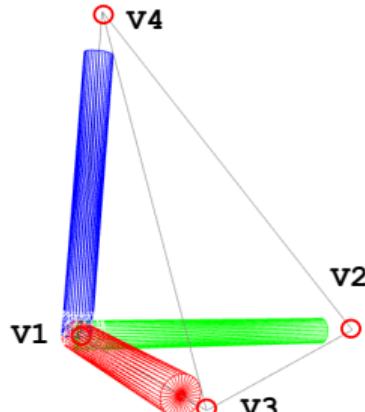
3DSCAN: static 3D model indexing overview



Raw File (.obj)

```
01 g tetrahedron
02 v 0.00 0.00 0.00 # v1
03 v 1.00 0.00 0.00 # v2
04 v 0.00 1.00 0.00 # v3
05 v 0.00 0.00 1.00 # v4
06
07
08 f 1 3 2      # v1 v3 v2
09 f 1 4 3      # v1 v4 v3
10 f 1 2 4      # v1 v2 v4
11 f 2 3 4      # v2 v3 v4
```

3DSCAN: static 3D model indexing overview



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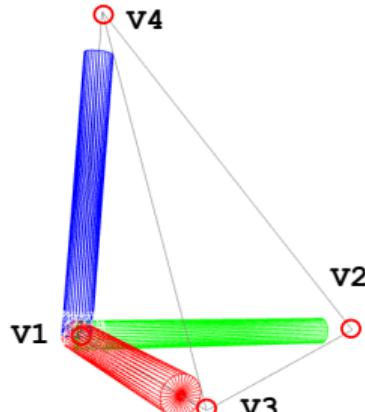
```
01 g tetrahedron
02 v 0.00 0.00 0.00 # v1
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04 v 0.00 1.00 0.00 # v3
05 v 0.00 0.00 1.00 # v4
06
07
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09 f 1 4 3      # v1 v4 v3
10 f 1 2 4      # v1 v2 v4
11 f 2 3 4      # v2 v3 v4
```

①
Sort



1	2	3	4
v2	v3	v4	v1

3DSCAN: static 3D model indexing overview



Raw File (.obj)

```
01 g tetrahedron
02 v 0.00 0.00 0.00 # v1
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① Sort



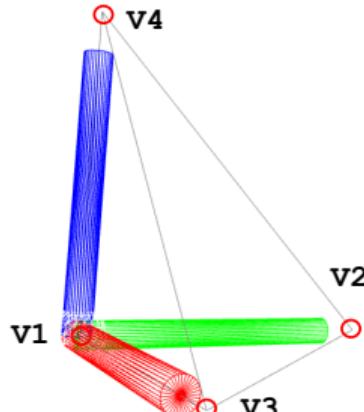
1	2	3	4
v2	v3	v4	v1

② Map



f	4	2	1
f	4	3	2
f	4	1	3
f	1	2	3

3DSCAN: static 3D model indexing overview



Raw File (.obj)

```

01 g tetrahedron
02 v 0.00 0.00 0.00 # v1
03 v 1.00 0.00 0.00 # v2
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```

①
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1	2	3	4
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②
Map

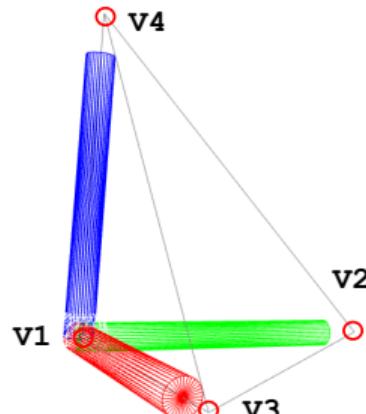
f	4	2	1
f	4	3	2
f	4	1	3
f	1	2	3



③
Sort

f	4	3	2
f	4	3	1
f	4	2	1
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3DSCAN: static 3D model indexing overview



Raw File (.obj)

```

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04 v 0.00 1.00 0.00 # v3
05 v 0.00 0.00 1.00 # v4
06
07
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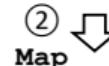
① Sort



1	2	3	4
v2	v3	v4	v1

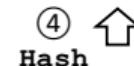
index

② Map



f	4	2	1
f	4	3	2
f	4	1	3
f	1	2	3

④ Hash



f	4	3	2
f	4	3	1
f	4	2	1
f	3	2	1

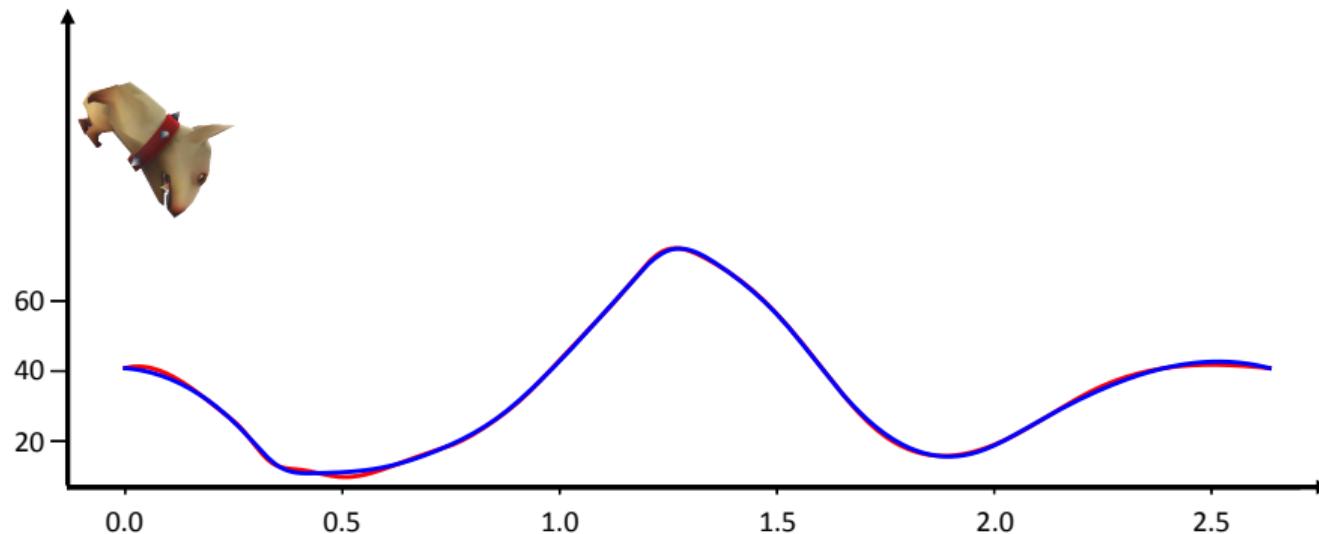
② Map



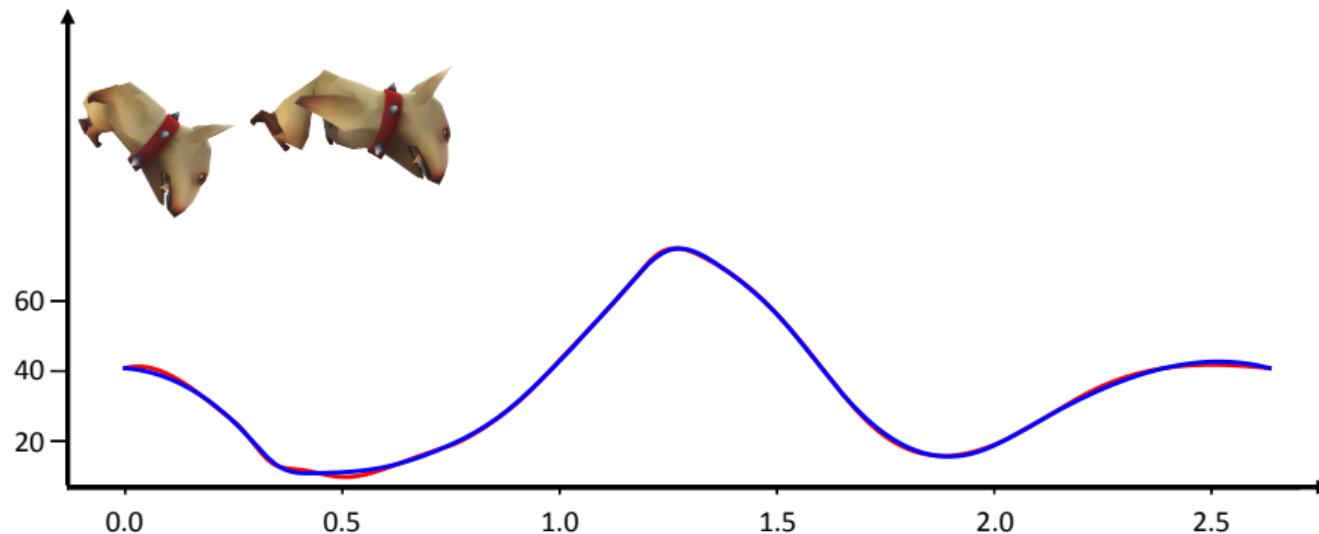
③ Sort



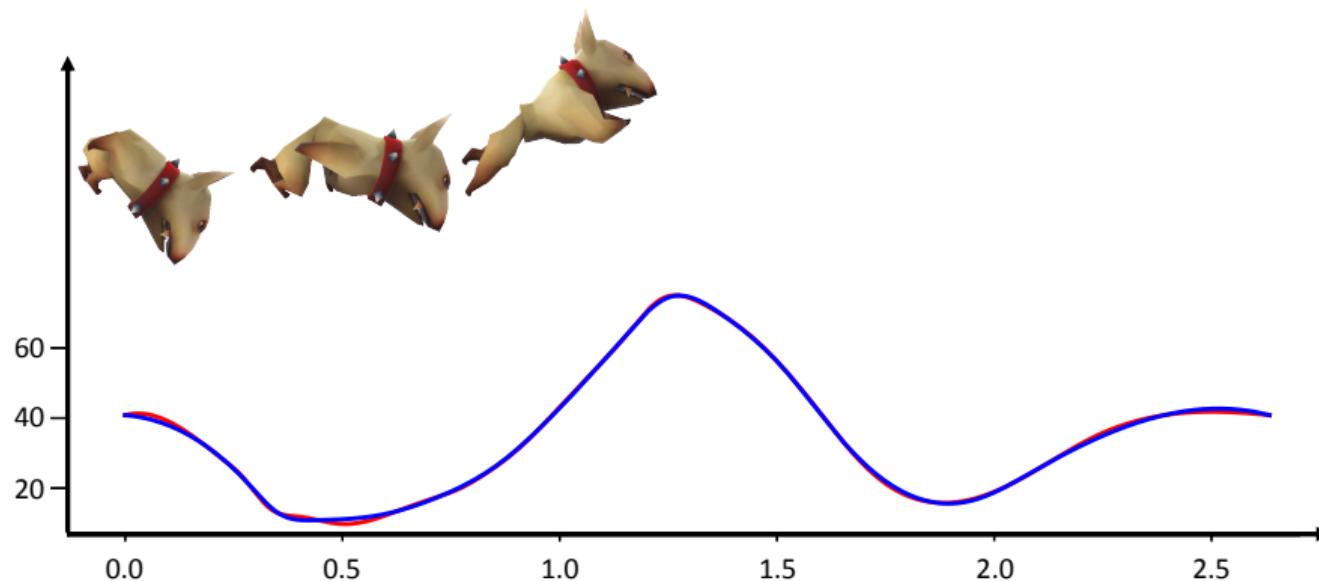
3DSCAN: animated 3D model interpolating overview



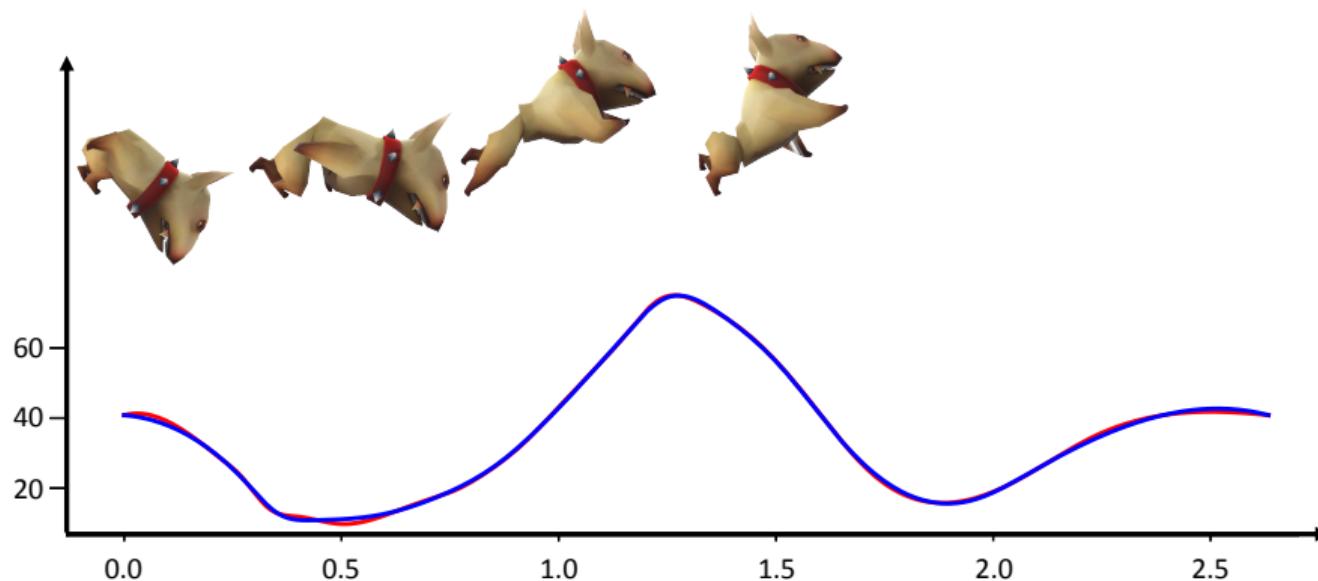
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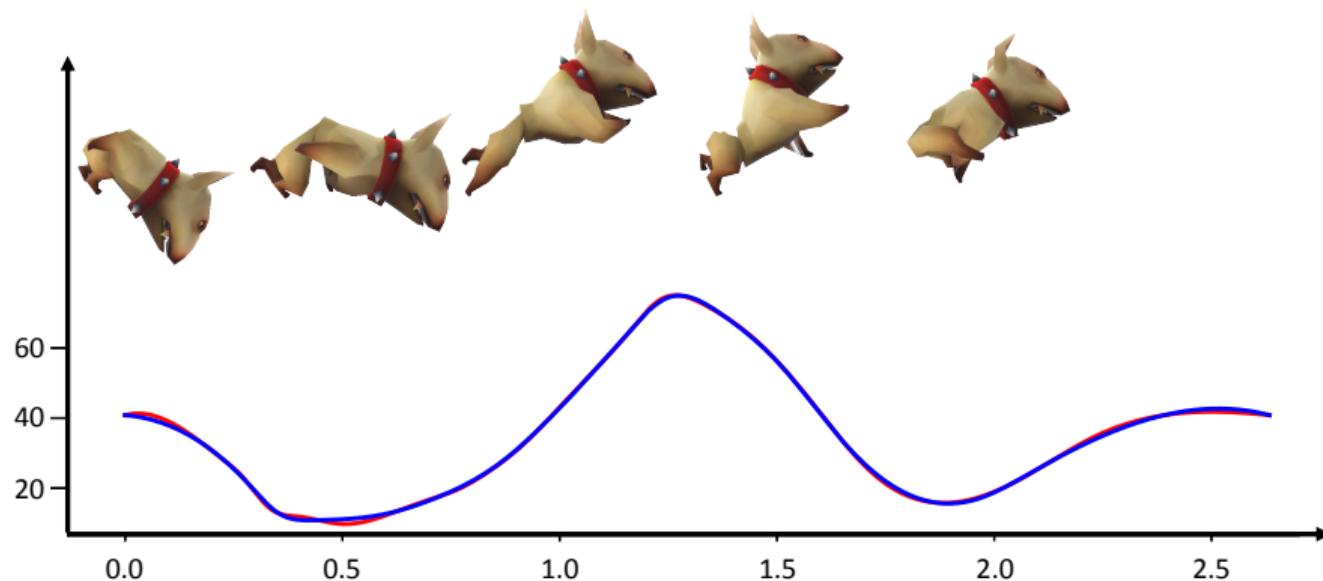
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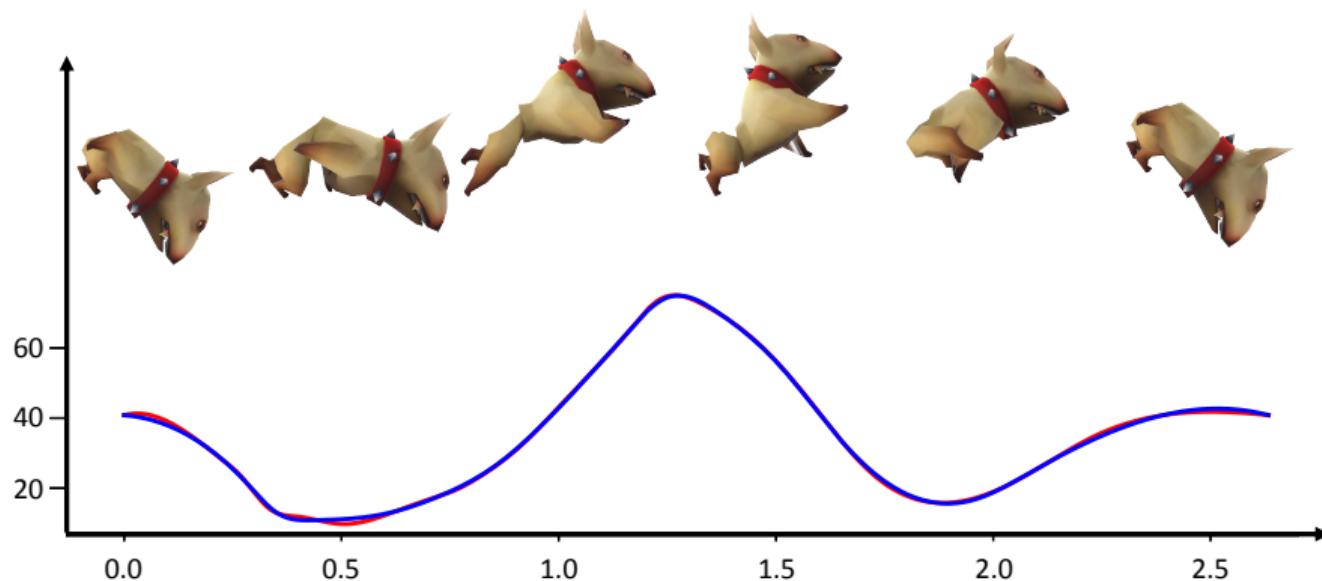
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Experiment setup

Dataset

- ▶ Downloaded by gplaycli
- ▶ **176,361** Unity-based games
- ▶ Over **5 TB** of storage

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Logistics

- ▶ **89,519** of the games containing 3D models
- ▶ **22,517,361** static 3D models
- ▶ **7,696,801** animated 3D models

Identified cloned 3D models

Cloned static 3D models

- ▶ **5,557,146** distinct static 3D models
- ▶ **1,046,632** 3D models being found in different games
- ▶ More than **80%** distinct models only exist in one game

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Cloned dynamic 3D models

- ▶ **1,722,795** distinct dynamic 3D models
- ▶ More than **1.5M (88%)** animated 3D models exist only in one game
- ▶ Most of them (**94%**) exist in one or two games

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Static 3D model clone is more common than dynamic model clone

3D models distribution across games

- Popular games tend to have more models, but the model complexity is decreasing

# Installs	# Games	(I)				(II)		(III)					
		Static 3D Models		Animated 3D Models		Model Average		Distinct Model		Model Clones			
		Total	Average	Total	Average	Vertices	Faces	Static	Animated	Static	Animated	Average	
500	33,182	4,969,430	149.76	1,357,767	40.92	1,766.91	1,470.54	1,404,839	338,742	409,252	72,485	14.52	
1K	13,177	2,948,531	223.76	919,989	69.82	1,612.37	1,325.13	918,647	198,108	398,695	62,881	35.03	
5K	5,475	1,392,774	254.39	429,659	78.48	1,646.80	1,341.39	515,873	114,060	241,060	35,022	50.43	
10K	11,659	3,389,492	290.72	1,249,804	107.20	1,630.57	1,320.78	1,033,665	247,982	452,565	68,981	44.73	
50K	4,528	1,468,631	324.34	540,708	119.41	1,729.43	1,378.50	486,907	137,904	264,041	33,113	65.63	
100K	9,460	2,998,522	316.97	1,161,467	122.78	1,613.92	1,318.86	949,642	226,499	428,137	67,664	52.41	
500K	3,457	1,265,555	366.08	446,742	129.23	1,592.51	1,309.02	476,733	133,743	242,269	37,844	81.03	
1M	5,521	2,323,020	420.76	796,189	144.21	1,277.82	1,040.69	961,134	371,945	350,072	43,033	71.20	
5M	1,313	663,554	505.37	234,583	178.66	1,291.44	1,038.19	285,578	88,566	122,666	16,824	106.24	
10M	1,448	890,168	614.76	473,049	326.69	1,000.09	825.86	483,649	131,387	174,879	25,898	138.66	
50M	202	152,370	754.31	60,573	299.87	853.12	756.63	77,433	12,977	29,382	1,798	154.36	
100M	89	51,016	573.21	23,896	268.49	923.47	838.93	37,040	5,664	10,367	364	120.57	
500M	7	2,934	419.14	1,989	284.14	760.56	702.61	2,271	123	243	0	34.71	
1B	1	1,364	1,364.00	386	386.00	730.06	695.31	1,048	376	316	10	327.00	

3D models distribution across games

- Popular games tend to contain more cloned models

# Installs	# Games	(I)				(II)		(III)					
		Static 3D Models		Animated 3D Models		Model Average		Distinct Model		Model Clones			
		Total	Average	Total	Average	Vertices	Faces	Static	Animated	Static	Animated	Average	
500	33,182	4,969,430	149.76	1,357,767	40.92	1,766.91	1,470.54	1,404,839	338,742	409,252	72,485	14.52	
1K	13,177	2,948,531	223.76	919,989	69.82	1,612.37	1,325.13	918,647	198,108	398,695	62,881	35.03	
5K	5,475	1,392,774	254.39	429,659	78.48	1,646.80	1,341.39	515,873	114,060	241,060	35,022	50.43	
10K	11,659	3,389,492	290.72	1,249,804	107.20	1,630.57	1,320.78	1,033,665	247,982	452,565	68,981	44.73	
50K	4,528	1,468,631	324.34	540,708	119.41	1,729.43	1,378.50	486,907	137,904	264,041	33,113	65.63	
100K	9,460	2,998,522	316.97	1,161,467	122.78	1,613.92	1,318.86	949,642	226,499	428,137	67,664	52.41	
500K	3,457	1,265,555	366.08	446,742	129.23	1,592.51	1,309.02	476,733	133,743	242,269	37,844	81.03	
1M	5,521	2,323,020	420.76	796,189	144.21	1,277.82	1,040.69	961,134	371,945	350,072	43,033	71.20	
5M	1,313	663,554	505.37	234,583	178.66	1,291.44	1,038.19	285,578	88,566	122,666	16,824	106.24	
10M	1,448	890,168	614.76	473,049	326.69	1,000.09	825.86	483,649	131,387	174,879	25,898	138.66	
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FP/FN analysis

False positives

Dissimilar models identified as similar

- ▶ Randomly selected:
 - ▶ **1,000** static models
 - ▶ **1,000** dynamic models
- ▶ Manual reviewing found: **0** FP

FP/FN analysis

False positives

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 - ▶ **1,000** static models
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- ▶ Manual reviewing found: **0** FP

False negatives

Appear identical but bear different hashes

- ▶ Gathered **50** common object words
 - ▶ **30** models in each group
 - ▶ **1,500** models in total
- ▶ Manual reviewing found: **0** FN

Manually reviewing results

Game clone

- ▶ Attackers may repackage an existing game
- ▶ The original game and the repackaged one would exhibit a high overlapping rate

	Victim Game	# Install	Category	Developer	Game w/ Cloned Models	# Install	Category	Developer	Removed?
Game Clone	Flip Diving	50M	Sports	MotionVolt Games Ltd	Cliff Diving	5K	Simulation	BBLoveG	✓
	Zombie 3D Gun Shooter	10M	Arcade	Fun Shooting Games .	Unkilled Hunter	1K	Action	Bsbh Studio	✓
	Agent Action	10M	Action	Saygames Ltd	Agent Legend	100	Adventure	Keep200019	✓
	Bike Racer	10M	Racing	Games Saga	Stunt Bike Racer 3D	100	Simulation	Liudingjun	✓
	Shoot Goal	10M	Sports	Bambo Studio	Dream Football Strike	10K	Sports	Crazy Sports Co.	✓
Idea Clone	Temple Run	500M	Arcade	Imangi Studios	Eternal Parkour	500	Action	Mangoqueen	✓
	Join Clash 3D	100M	Arcade	Supersonic Studios LTD	Join Clash 3D: Crowd Rush	5K	Arcade	Gamezo	✓
	Talking Tom Hero Dash	100M	Action	Outfit7 Limited	Jungle Cat Runner	100	Role Playing	Vigour3D	✓
	Hungry Shark Evolution	100M	Arcade	Ubisoft Entertainment	Scuba Hunter	100	Adventure	Arcadian Lab	✗
	Robot Helicopter	5M	Action	Naxeex Robots	Us Army Robot Helicopter	5K	Strategy	Dreams Games Inc,	✓
Model Clone	Subway Surfers	1,000M	Arcade	Sybo Games	Bob The Robber Runner	100	Adventure	Appspres	✗
	Cover Strike	100M	Action	Free Actions	Military Commando Mission	1M	Adventure	New Games 2021 .	✓
	Color Bump 3D	100M	Arcade	Good Job Games	Color Bumper Ball	1K	Arcade	Coz Rdev	✗
	Flight Simulator	100M	Simulation	I6 Games	Airplane Free Fly Simulator	10K	Simulation	Bf Games Studio	✓
	Bridge Race	100M	Casual	Supersonic Studios Ltd	Tower Stack	1K	Casual	Jacob Van Haag	✓

Manually reviewing results

Idea clone

- Attacker may replicate the idea by creating a similar game
- This replication could possibly appropriate some models from the original game

	Victim Game	# Install	Category	Developer	Game w/ Cloned Models	# Install	Category	Developer	Removed?
Game Clone	Flip Diving	50M	Sports	MotionVolt Games Ltd	Cliff Diving	5K	Simulation	BBLoveG	✓
Idea Clone	Zombie 3D Gun Shooter	10M	Arcade	Fun Shooting Games .	Unkilled Hunter	1K	Action	Bsbh Studio	✓
Agent Action	10M	Action	Saygames Ltd	Agent Legend	100	Adventure	Keep200019	✓	
Bike Racer	10M	Racing	Games Saga	Stunt Bike Racer 3D	100	Simulation	Liudingjun	✓	
Shoot Goal	10M	Sports	Bambo Studio	Dream Football Strike	10K	Sports	Crazy Sports Co.	✓	
Temple Run	500M	Arcade	Imangi Studios	Eternal Parkour	500	Action	Mangoqueen	✓	
Join Clash 3D	100M	Arcade	Supersonic Studios LTD	Join Clash 3D: Crowd Rush	5K	Arcade	Gamezo	✓	
Talking Tom Hero Dash	100M	Action	Outfit7 Limited	Jungle Cat Runner	100	Role Playing	Vigour3D	✓	
Hungry Shark Evolution	100M	Arcade	Ubisoft Entertainment	Scuba Hunter	100	Adventure	Arcadian Lab	✗	
Robot Helicopter	5M	Action	Naxeex Robots	Us Army Robot Helicopter	5K	Strategy	Dreams Games Inc.	✓	
Model Clone	Subway Surfers	1,000M	Arcade	Sybo Games	Bob The Robber Runner	100	Adventure	Appspres	✗
Cover Strike	100M	Action	Free Actions	Military Commando Mission	1M	Adventure	New Games 2021 .	✓	
Color Bump 3D	100M	Arcade	Good Job Games	Color Bumper Ball	1K	Arcade	Coz Rdev	✗	
Flight Simulator	100M	Simulation	l6 Games	Airplane Free Fly Simulator	10K	Simulation	Bf Games Studio	✓	
Bridge Race	100M	Casual	Supersonic Studios Ltd	Tower Stack	1K	Casual	Jacob Van Haag	✓	

Manually reviewing results

Model clone

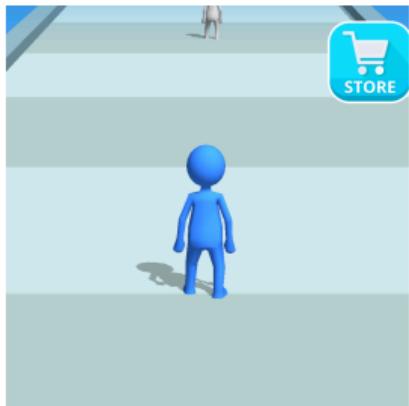
- Attacker may be interested in a specific model
- Steal the specific model and use it in a game belonging to a different category

	Victim Game	# Install	Category	Developer	Game w/ Cloned Models	# Install	Category	Developer	Removed?
Game Clone	Flip Diving	50M	Sports	MotionVolt Games Ltd	Cliff Diving	5K	Simulation	BBLoveG	✓
Idea Clone	Zombie 3D Gun Shooter	10M	Arcade	Fun Shooting Games .	Unkilled Hunter	1K	Action	Bsbh Studio	✓
Agent Action	10M	Action	Saygames Ltd	Agent Legend	100	Adventure	Keep200019	✓	
Bike Racer	10M	Racing	Games Saga	Stunt Bike Racer 3D	100	Simulation	Liudingjun	✓	
Shoot Goal	10M	Sports	Bambo Studio	Dream Football Strike	10K	Sports	Crazy Sports Co.	✓	
Model Clone	Temple Run	500M	Arcade	Imangi Studios	Eternal Parkour	500	Action	Mangoqueen	✓
Join Clash 3D	100M	Arcade	Supersonic Studios LTD	Join Clash 3D: Crowd Rush	5K	Arcade	Gamezo	✓	
Talking Tom Hero Dash	100M	Action	Outfit7 Limited	Jungle Cat Runner	100	Role Playing	Vigour3D	✓	
Hungry Shark Evolution	100M	Arcade	Ubisoft Entertainment	Scuba Hunter	100	Adventure	Arcadian Lab	✗	
Robot Helicopter	5M	Action	Naxeex Robots	Us Army Robot Helicopter	5K	Strategy	Dreams Games Inc,	✓	
Model Clone	Subway Surfers	1,000M	Arcade	Sybo Games	Bob The Robber Runner	100	Adventure	Appspres	✗
Cover Strike	100M	Action	Free Actions	Military Commando Mission	1M	Adventure	New Games 2021 .	✓	
Color Bump 3D	100M	Arcade	Good Job Games	Color Bumper Ball	1K	Arcade	Coz Rdev	✗	
Flight Simulator	100M	Simulation	i6 Games	Airplane Free Fly Simulator	10K	Simulation	Bf Games Studio	✓	
Bridge Race	100M	Casual	Supersonic Studios Ltd	Tower Stack	1K	Casual	Jacob Van Haag	✓	

Real cases

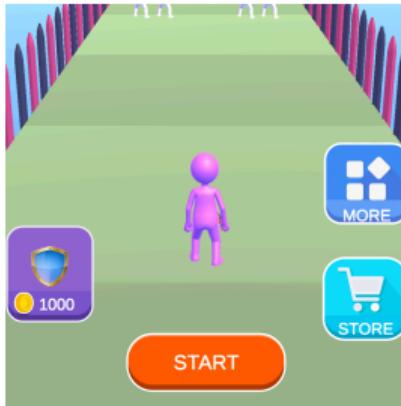


Victim



Join Clash 3D

Suspicion



Join Clash 3D: Crowd Rush

Real cases



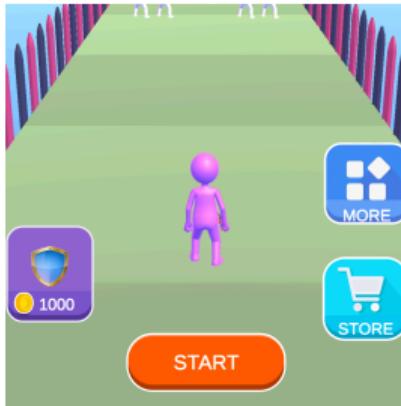
Victim



Join Clash 3D

100M+ installs

Suspicion

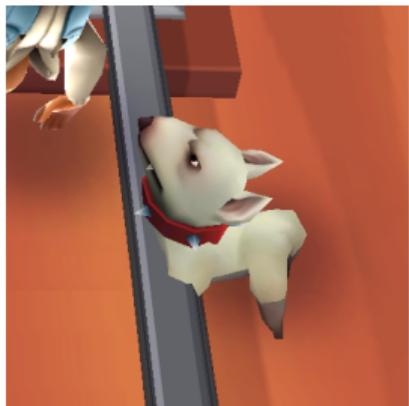


Join Clash 3D: Crowd Rush

5K+ installs

Real cases

Victim



Subway Surfers

Suspicion

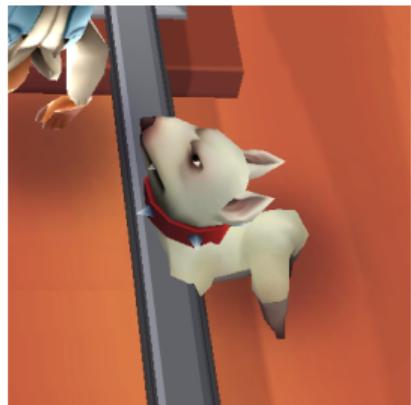


Bob The Robber Runner

Real cases



Victim



Subway Surfers

1B+ installs

Suspicion



Bob The Robber Runner

100+ installs

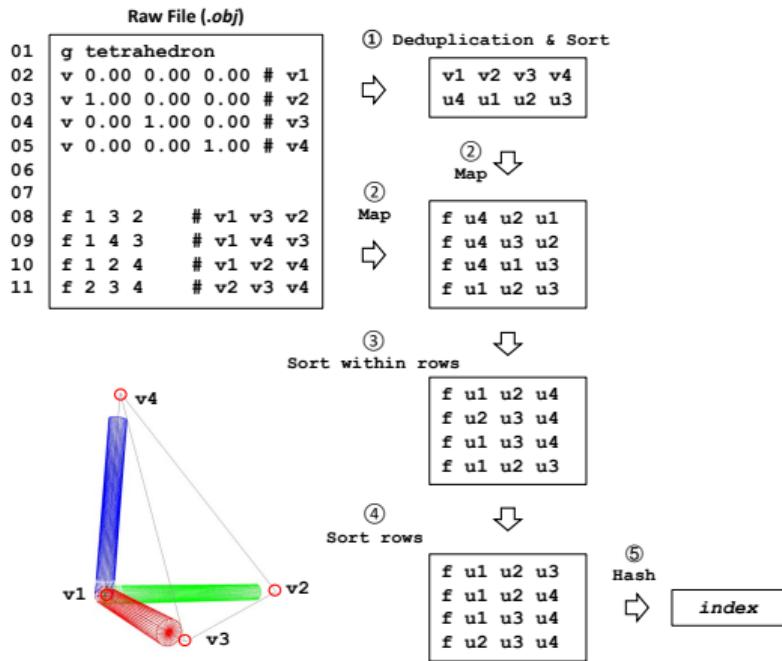
Conclusion

3DSCAN

- First **open source**, robust tool designed to identify 3D model clones within the mobile gaming sector

Evaluated w/ 176K+ mobile games

- **Empirical Results.** Identified **63.03%** static, **37.07%** animated 3D models are subject to cloning
- **Unauthorized Clone Detection.** Identified **5,238** mobile games likely containing unauthorized clones



Q&A

3DSCAN Source Code

<https://github.com/OSUSecLab/3DScan>

SecLab @ OSU

<https://go.osu.edu/seclab>