

[ASE 25] VRExplorer: A Model-based Approach for Semi-Automated Testing of Virtual Reality Scenes

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■ Research Background

- Manual VR testing is **labor-intensive and inefficient**
- **Limitation of SOTA: VRTest** (ICSE 22 short) & **VRGuide** (only can `click`, struggle to perform other VR-specific actions)
- **Limitation of CV/LLM Methods:** only analyze screenshots, **lack code execution capability**)
- **Core Challenge:** It remains difficult to test VR apps comprehensively and efficiently

Introduction



■ An Example of Challenge

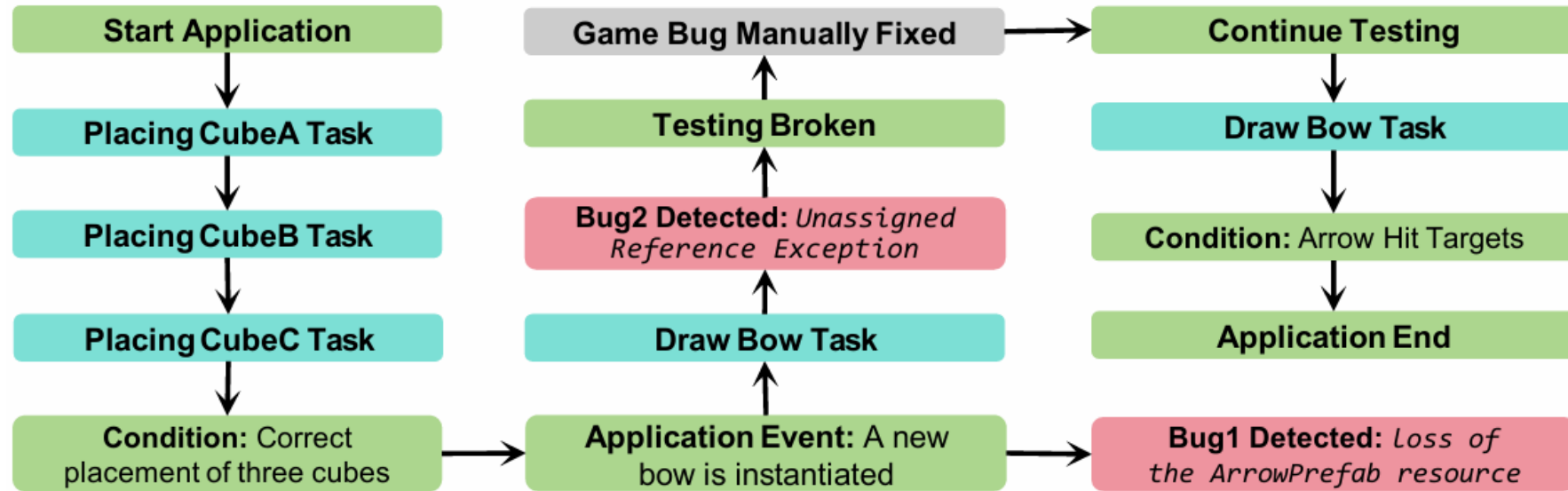


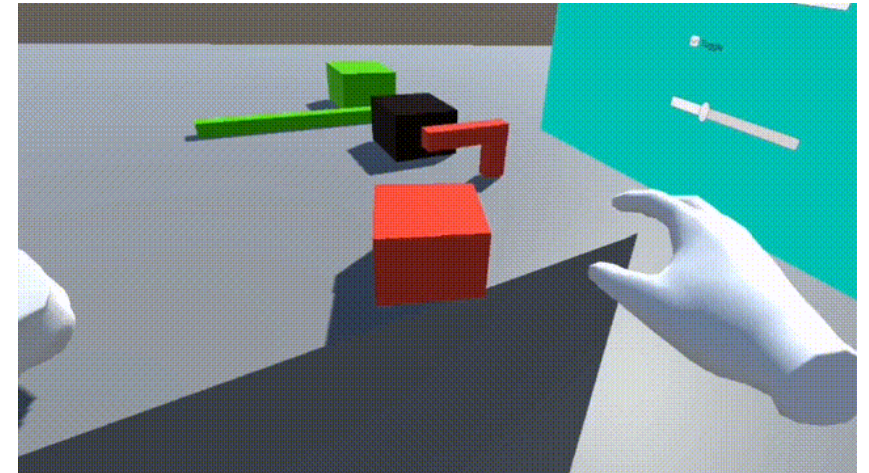
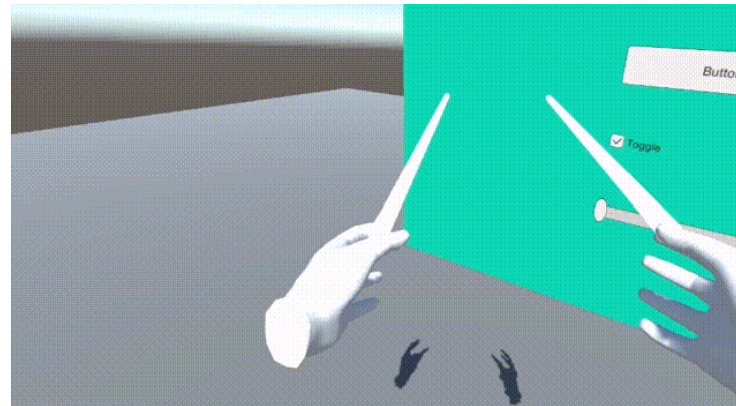
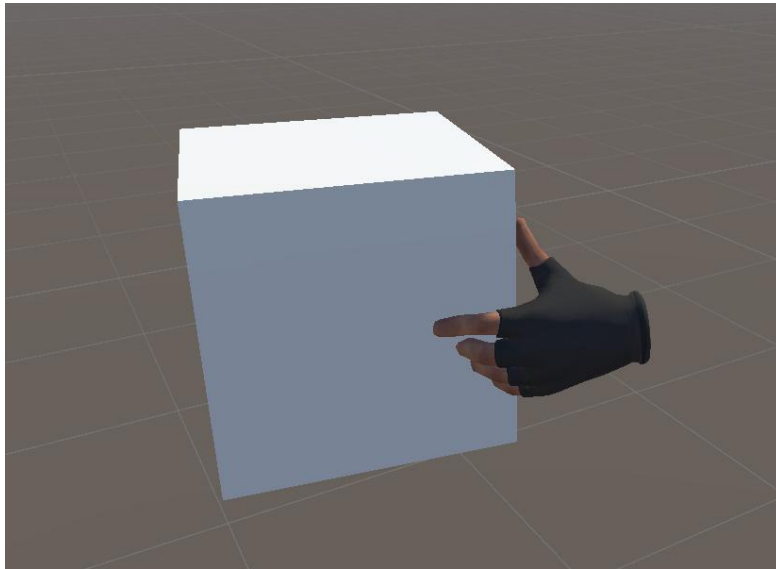
Fig. 9: Testing Process of EscapeGameVR

Introduction



■ Challenges

- **Diversity of interactions** (Grab, Move, Throw, Raycast, Press, Touch, Pull, Trigger, Transform, Shoot/Fire)



Introduction



■ Challenges

- Diversity of interactions

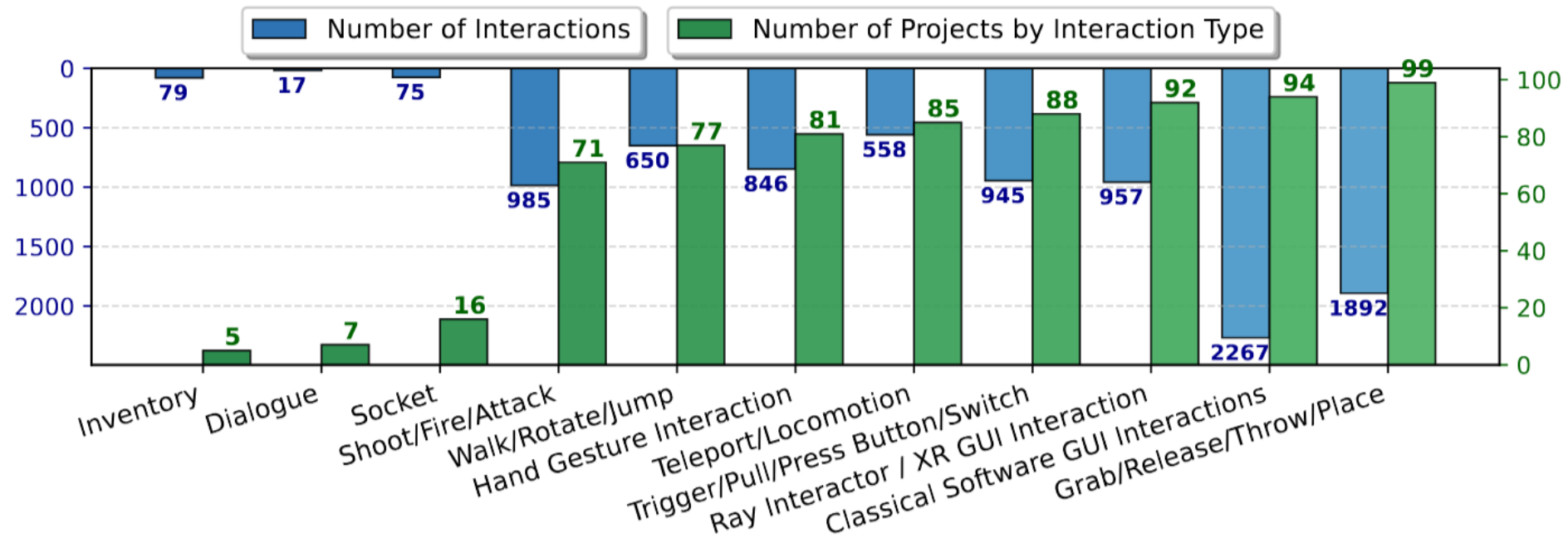


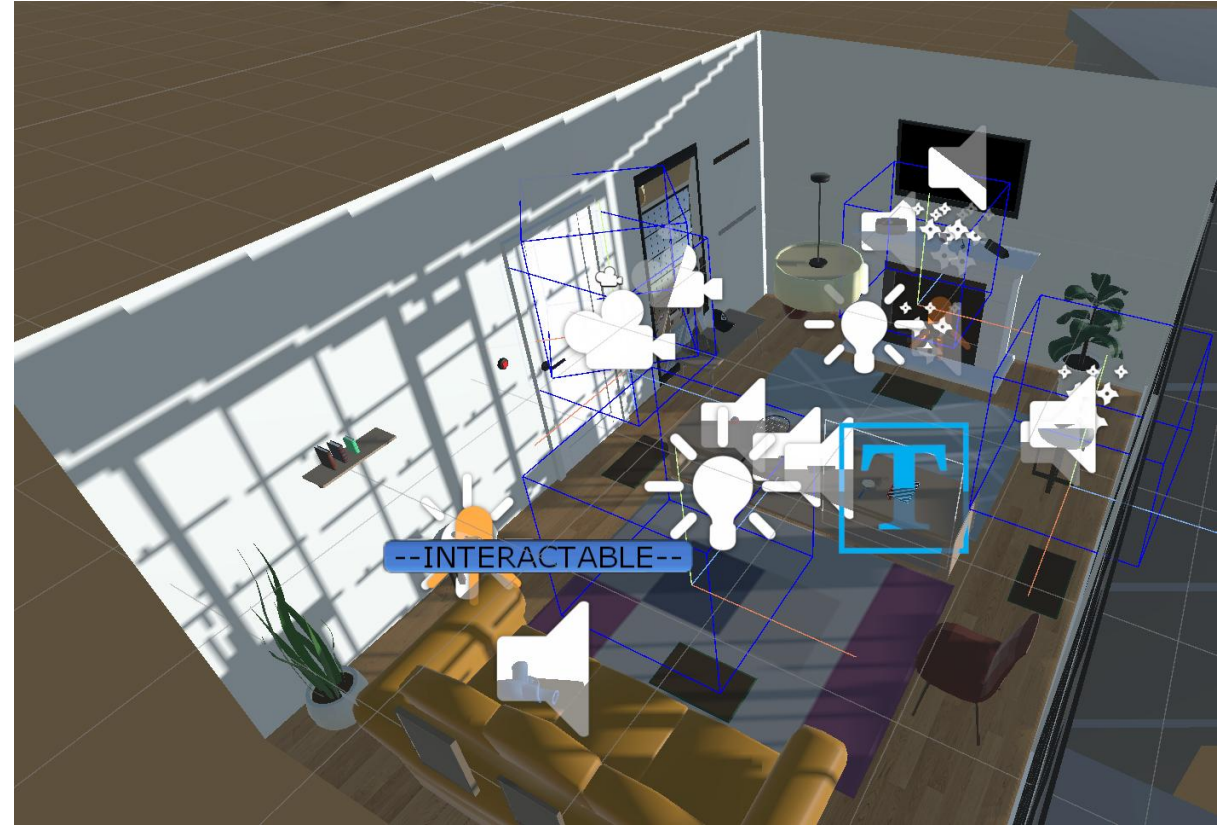
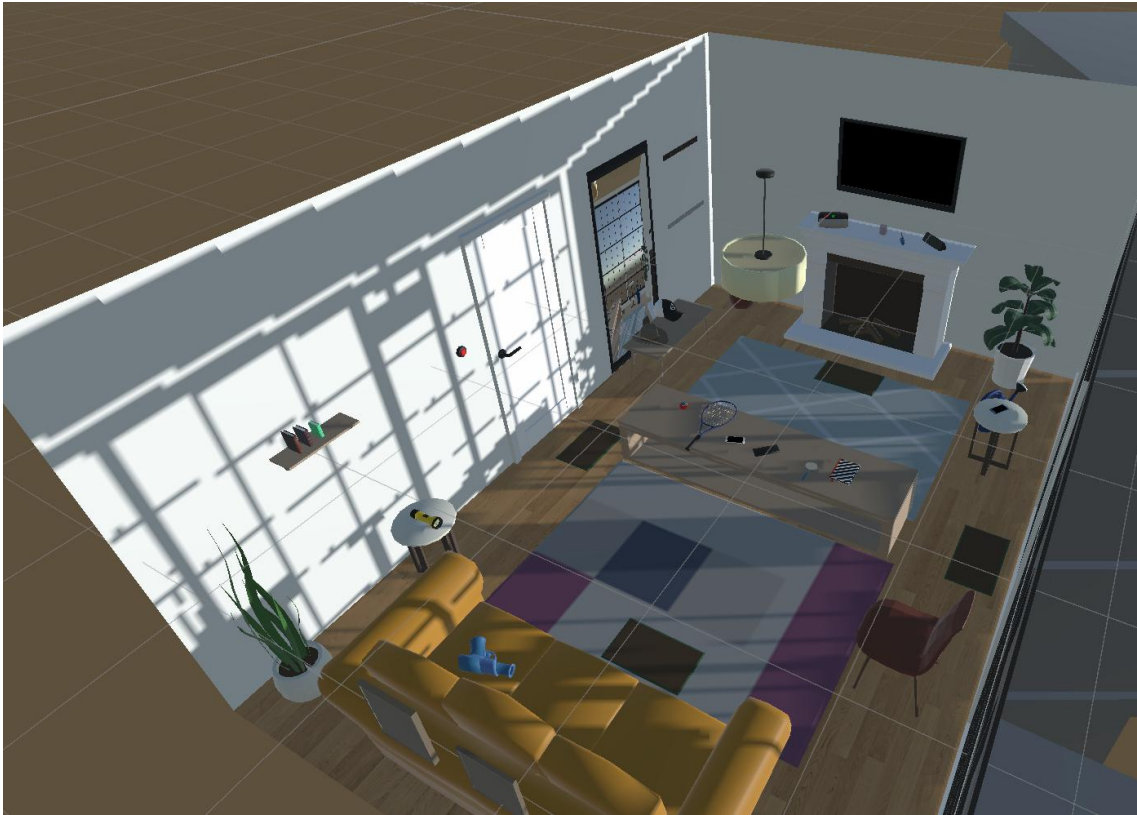
Fig. 6: Distribution of Interactions in Dataset.

Introduction



■ Challenges

- Complex3D virtual environments

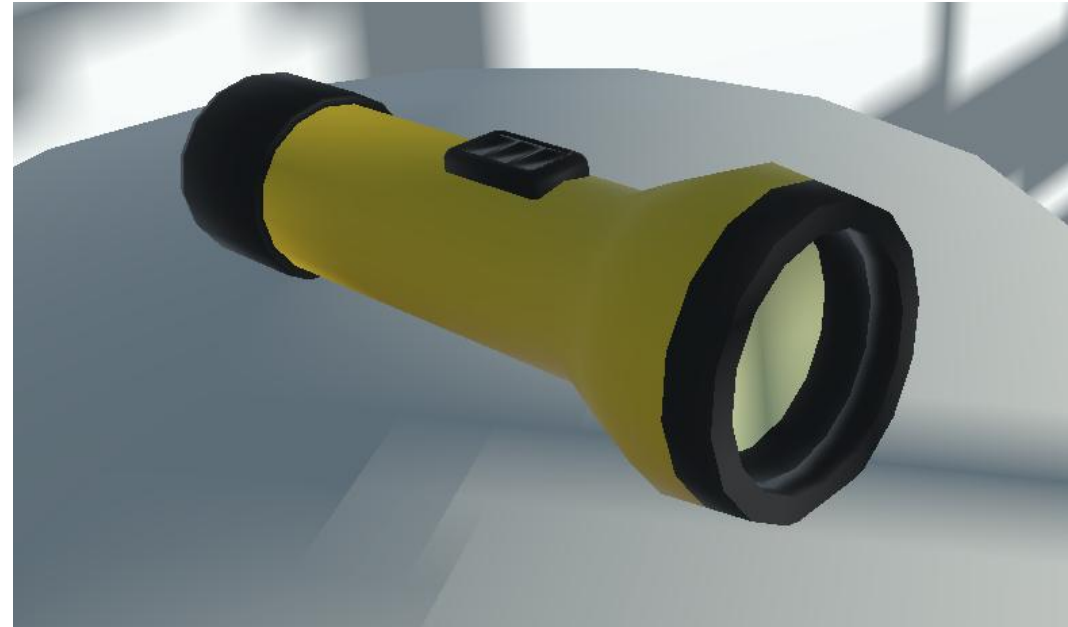


Introduction



■ Challenges

- **Sequence of tasks** (find a key -> open a door -> turn a handle -> finally pressing a button to escape; Grab a Lighter -> light a candle, Grab a light source -> press buttons)



Approach



■ Contribution and Novelty

➤ To solve these challenges

1. Model Abstraction

2. EAT Framework (based on OOP)

3. VRExplorer Agent (Automated Exploration of Scenes)

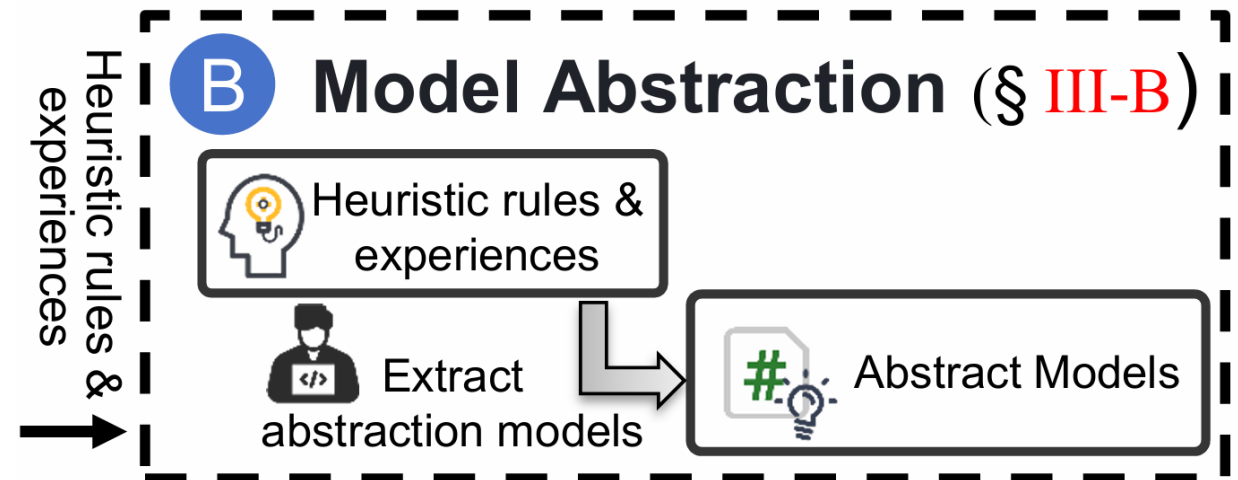
Approach



■ Contribution and Novelty

➤ Model Abstraction

Project Analysis (by
Experienced Test Engineers)



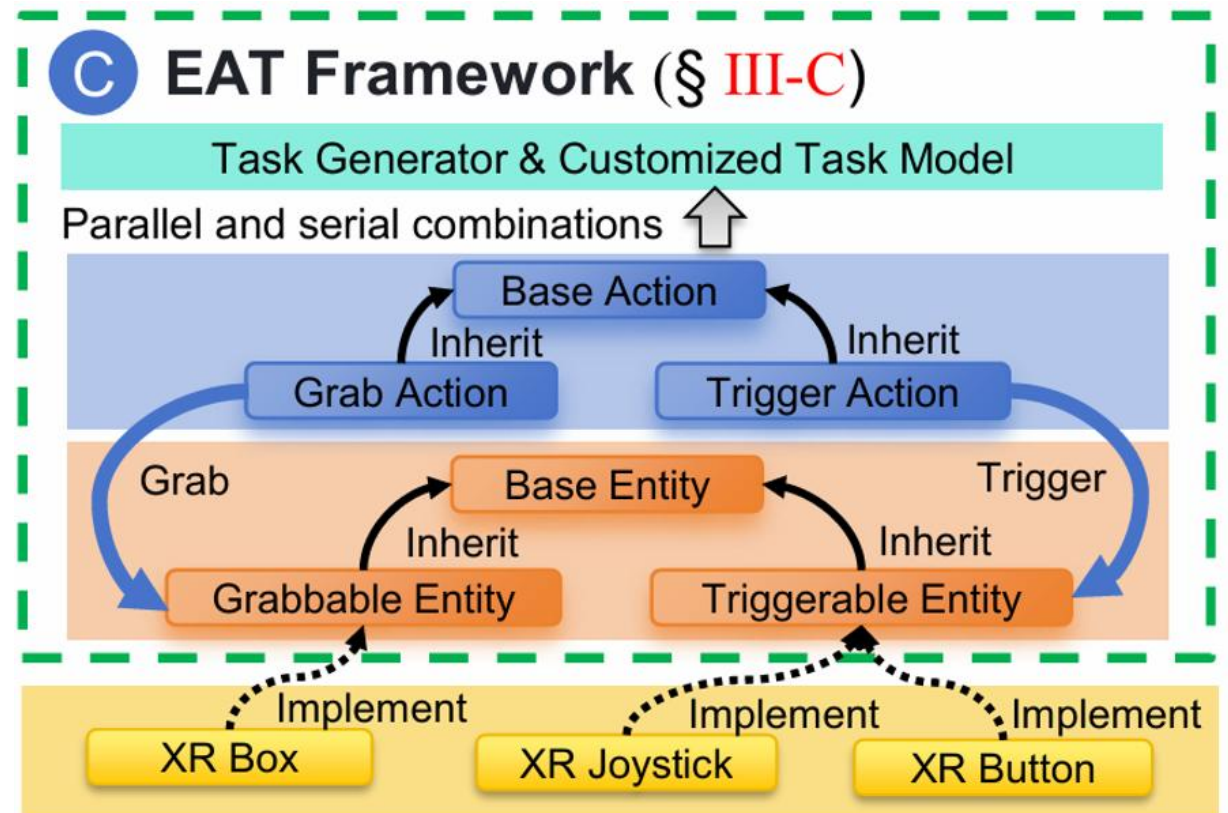
Approach



■ Contribution and Novelty

➤ EAT Framework (based on OOP)

- **Entity:** Abstract Interactables
- **Action:** Abstract VR Actions
- **Task:** Abstract Action Sequences

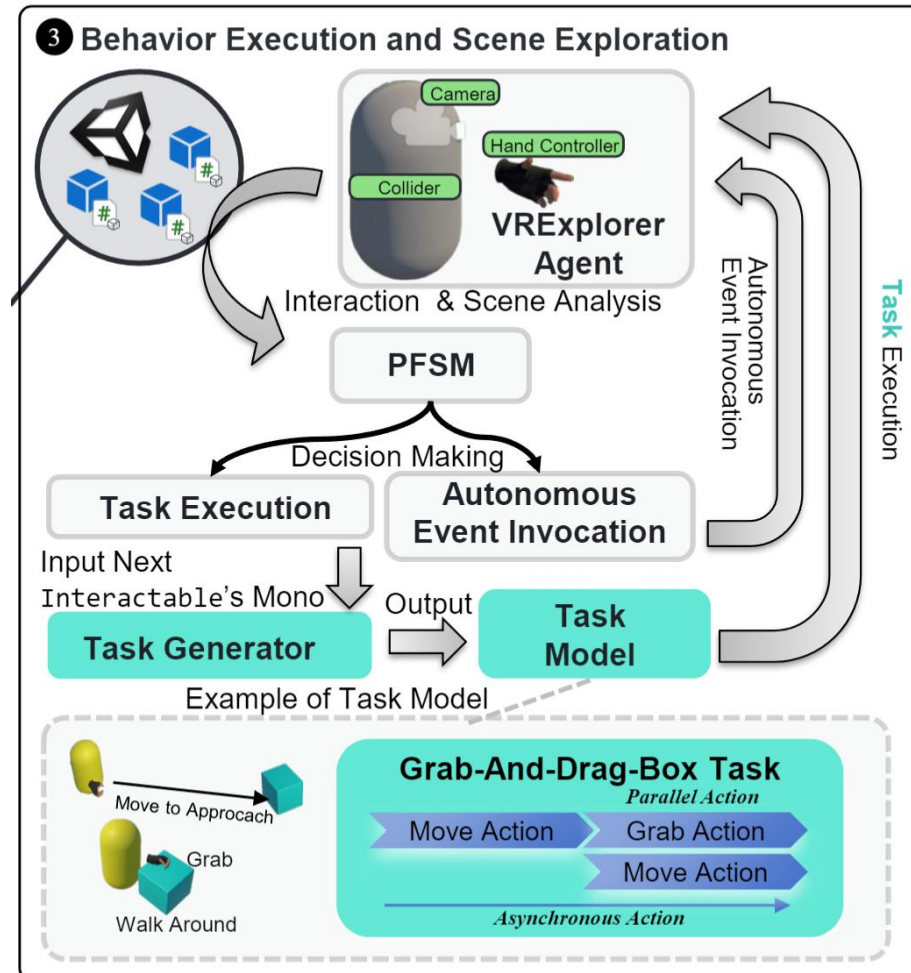


Approach



■ Contribution and Novelty

➤ VRExplorer Agent



Approach



Overview

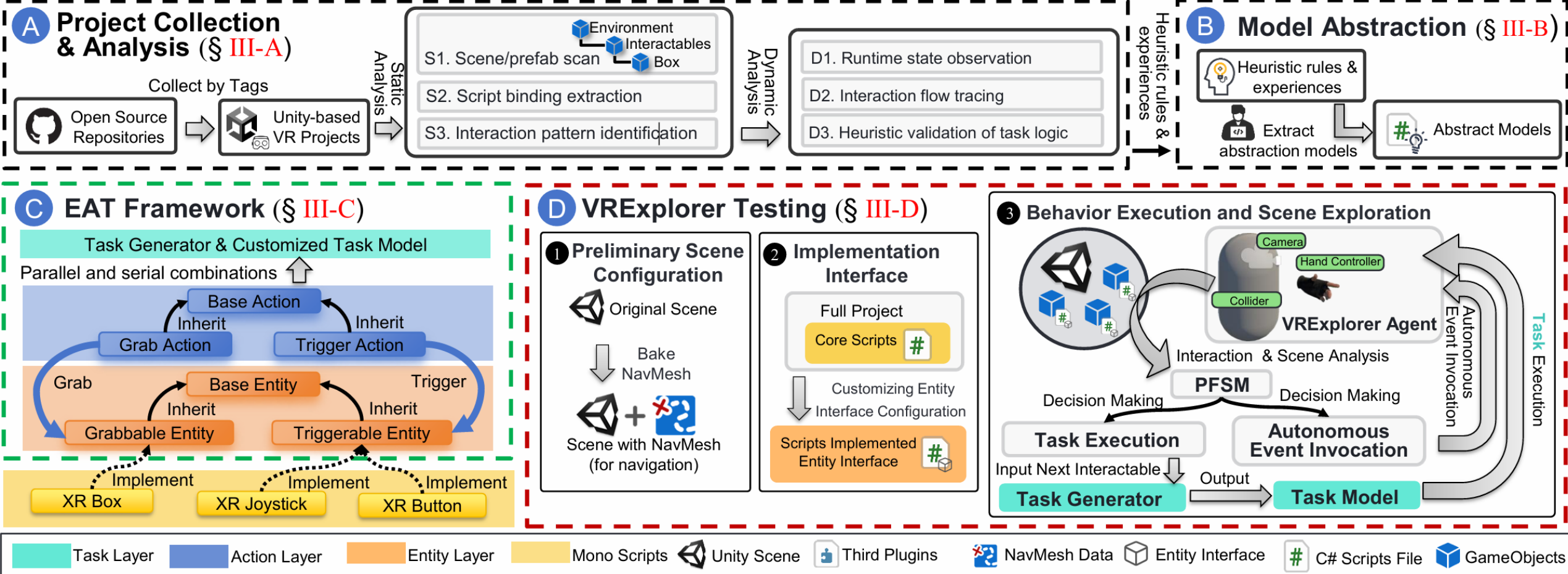


Fig. 1: Overview of *VRExplorer*

Evaluation of VRExplorer



■ Evaluation Projects

- We evaluate VRExplorer on 11 representative VR projects
- +122.8% Executable Lines of Code Cov. vs SOTA
- +52.8% Method Cov. vs SOTA
- successfully detected 3 real-world bugs.

Evaluation of VRExplorer



■ Evaluation Projects

➤ Evaluation on Complex 3D VR Projects

TABLE V: Quantitative Metrics of Selected VR Projects

	Projects	# of Scripts	LOC	# of Files	Scenes	# of GOs	Version
Group 1	unity-vr-maze	158	25,261	212	1	278	5.x
	UnityVR	150	24,858	330	3	124	2019.x
	UnityCityView	182	28,335	446	34	1,194	2019.x
Group 2	Parkinson-VR ¹	275	38,437	968	33	1,566	2019.x
	VGuns	81	10,900	848	36	1,653	2020.x
	EE-Room ²	88	4,450	1,063	8	1,517	2020.x
	EscapeGameVR	91	6,659	1,377	44	8,256	2021.x
	VRChess	160	26,591	414	4	280	2021.x
	VR-Basics	62	2,677	724	5	2,143	2021.x
	VR-Room	65	3,660	679	2	414	2022.x
	VR-Adventure	11	260	91	2	288	2022.x

¹ Parkinson-VR stands for Parkinson-App-Virtual-Reality.

² EE-Room stands for Edutainment-Escape-Room.

Evaluation of VRExplorer



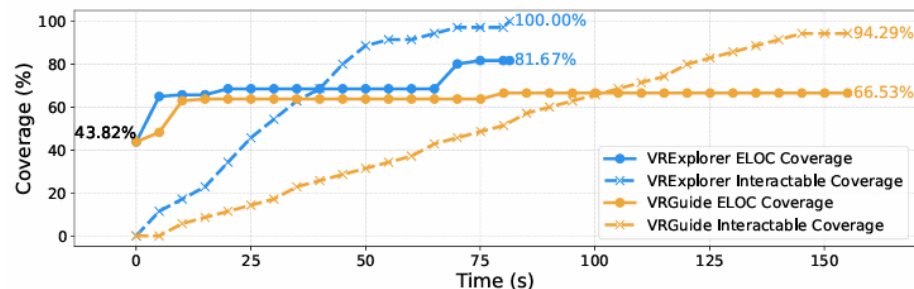
■ Types of evaluated applications

- (i) Action and Shooter (VGuns)
- (ii) Simulation (VR-Basics, VR-Room, Unity VR)
- (iii) Adventure (unity-vr-maze, VR-Adventure)
- (iv) Puzzle (Edutainment-Escape-Room, EscapeGameVR)
- (v) Medical Care (Parkinson-VR)
- (vi) Strategy Board Game (VRChess)

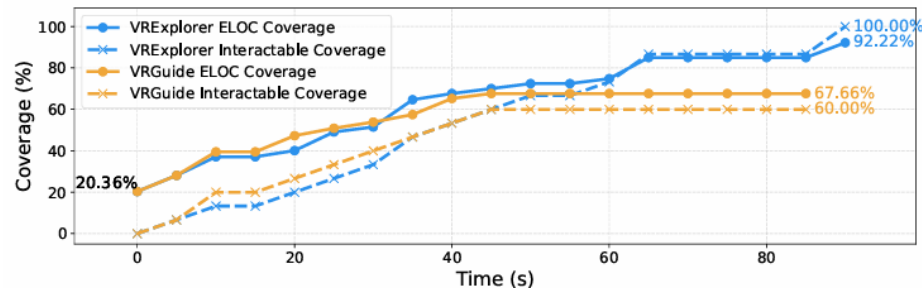
Evaluation of VRExplorer



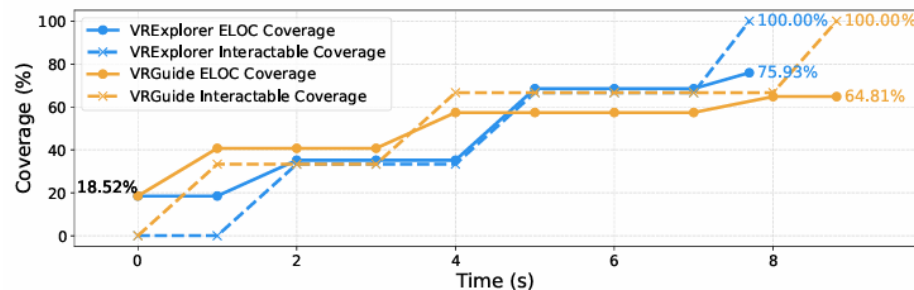
■ RQ1 (Performance vs SOTA)



(a) Coverage versus Time in Project unity-vr-maze



(b) Coverage versus Time in Project UnityCityView



(c) Coverage versus Time in Project UnityVR

Fig. 8: EC versus time during the testing process in Group 1.

Experiment



■ RQ1 (Performance vs SOTA)

$$G_{AB}(M) = \frac{P_A(M) - P_B(M)}{P_B(M)} \times 100\%,$$

TABLE V: Results on Projects in Group 1

Projects	Approaches	ELOC Coverage (%)	Method Coverage (%)	IO Coverage(%)	Convergence Time Cost (s)	# of Interactable Objects
unity-vr-maze	VRGuide	66.53	70.59	94.29	145.0	35
	VRExplorer	81.67 (+22.8%)	82.35 (+16.7%)	100.00 (+6.1%)	81.4 (-43.9%)	
UnityCityView	VRGuide	67.66	78.38	60.00	45.0	15
	VRExplorer	92.22 (+36.3%)	100.00 (+27.6%)	100.00 (+66.7%)	89.3 (+98.4%)	
UnityVR	VRGuide	64.81	84.62	100.00	8.8	3
	VRExplorer	75.93 (+17.1%)	92.31 (+9.1%)	100.00	7.7 (-12.5%)	

TABLE VI: Results on Projects of Group 2

Projects	Approaches	ELOC Coverage (%)	Method Coverage (%)
VR-Basics	VRGuide	41.38	53.22
	VRExplorer	80.17 (+93.8%)	91.93 (+72.8%)
VR-Room	VRGuide	40.97	50.63
	VRExplorer	77.61 (+89.4%)	83.54 (+65.0%)
VGuns	VRGuide	28.68	38.89
	VRExplorer	77.57 (+170.7%)	77.78 (+100.0%)
VR-Adventure	VRGuide	54.12	65.00
	VRExplorer	91.76 (+69.6%)	95.00 (+46.2%)
EE-Room	VRGuide	38.08	58.06
	VRExplorer	70.61 (+85.5%)	88.17 (+51.8%)
EscapeGameVR	VRGuide	41.77	55.26
	VRExplorer	71.08 (+70.2%)	73.68 (+33.3%)

**Answer to RQ1 (Performance):
Faster and Higher Coverage**

Experiment



- **RQ2: (Ablation Study)** How do different modules contribute to the performance of VRExplorer?

TABLE VII: Results of Ablation Study

Projects	Approaches	ELOC Coverage (%)	Method Coverage (%)
VR-Basics	VRGuide	41.38	53.22
	VRExplorer	<u>80.17</u>	<u>91.93</u>
	VRExplorer w/o T	68.10 (-15.0%)	77.42 (-15.9%)
	VRExplorer w/o Tf	59.24 (-26.1%)	70.00 (-16.2%)
VR-Room	VRGuide	40.97	50.63
	VRExplorer	<u>77.61</u>	<u>83.54</u>
	VRExplorer w/o G	58.52 (-24.6%)	69.62 (-16.4%)
	VRExplorer w/o T	64.12 (-17.3%)	67.00 (-19.7%)
VGuns	VRGuide	28.68	38.89
	VRExplorer	<u>77.57</u>	<u>77.78</u>
	VRExplorer w/o TG	50.37 (-35.3%)	61.11 (-16.7%)
	VRExplorer w/o AE	65.07 (-16.1%)	63.89 (-17.9%)

Answer to RQ2:
Interaction Modules
Contribute Marvelously

Experiment



■ RQ3: Can VRExplorer detect real-world VR bugs?

- 2 functional in projects EscapeGameVR and UnityCityView
- 1 non-functional bug in the project EscapeGameVR.

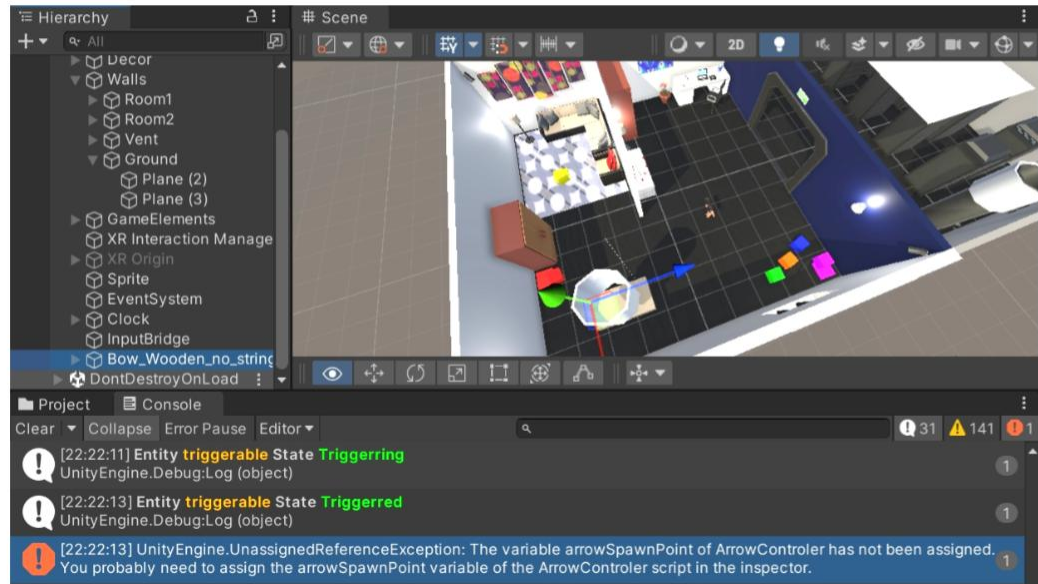


Fig. 7: A Detected Bug in EscapeGameVR

**Answer to RQ3:
capable of detecting
complex VR bugs**

Future Work



■ Future Work

➤ LLM + VRExplorer

- Fully automated VR testing agent
- Using LLM to generate testing actions

Acknowledgement



■ Acknowledgement

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