GHENT UNIVERSITY

Inference of Error Specifications and Bug Detection Using Structural Similarities

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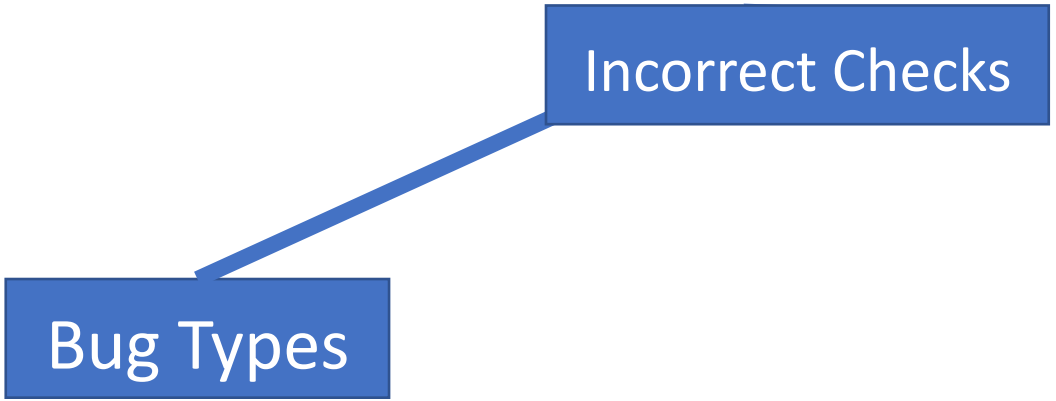
August 14 2024

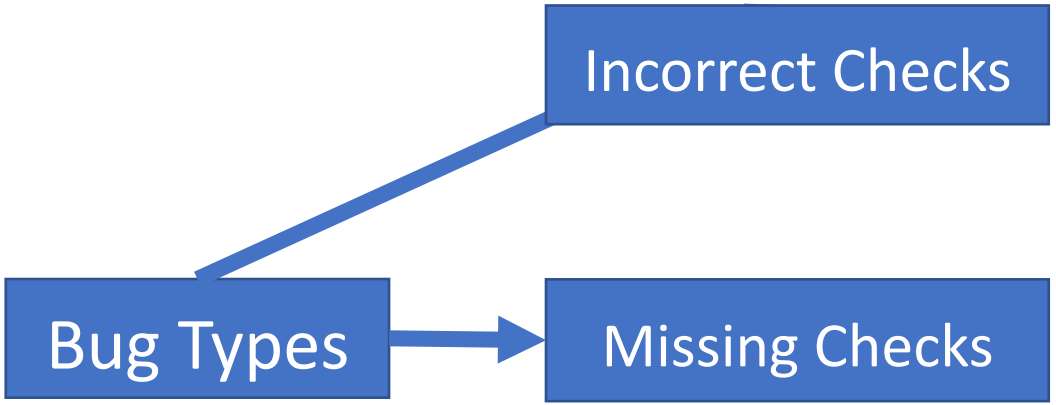
Error Check Bugs

Bug Types

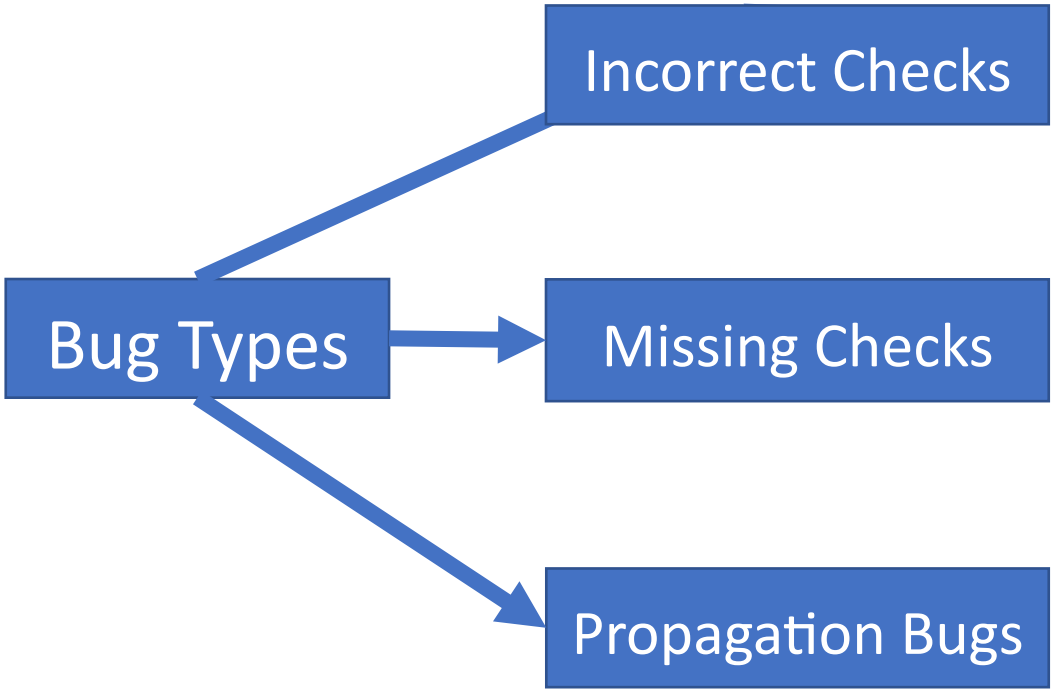
Error Check Bugs



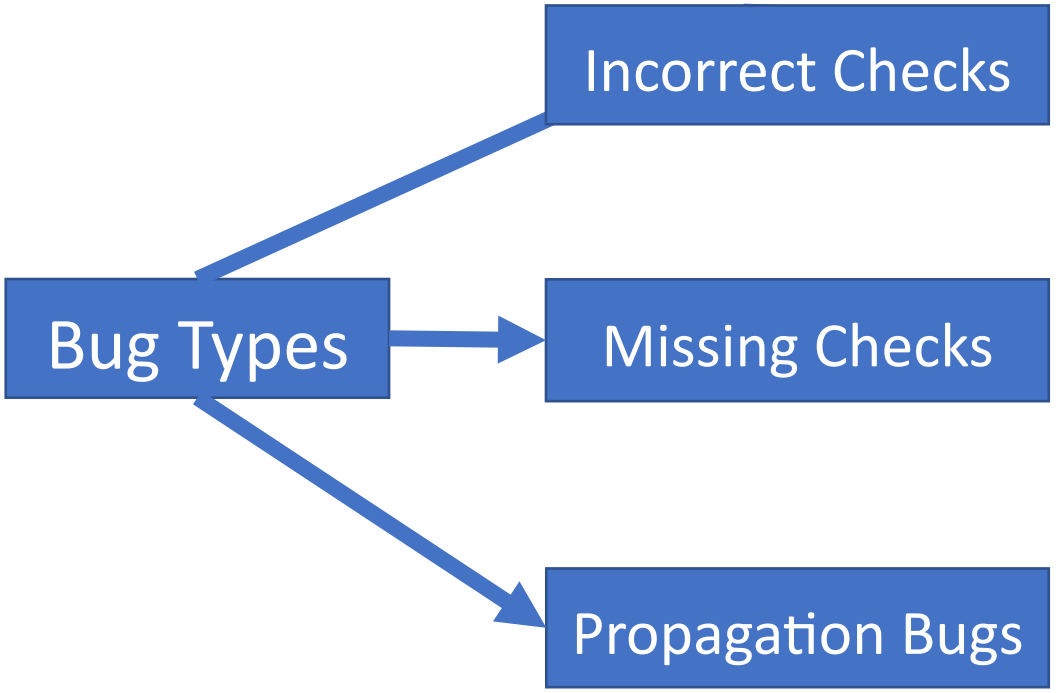
Error Check Bugs



Error Check Bugs

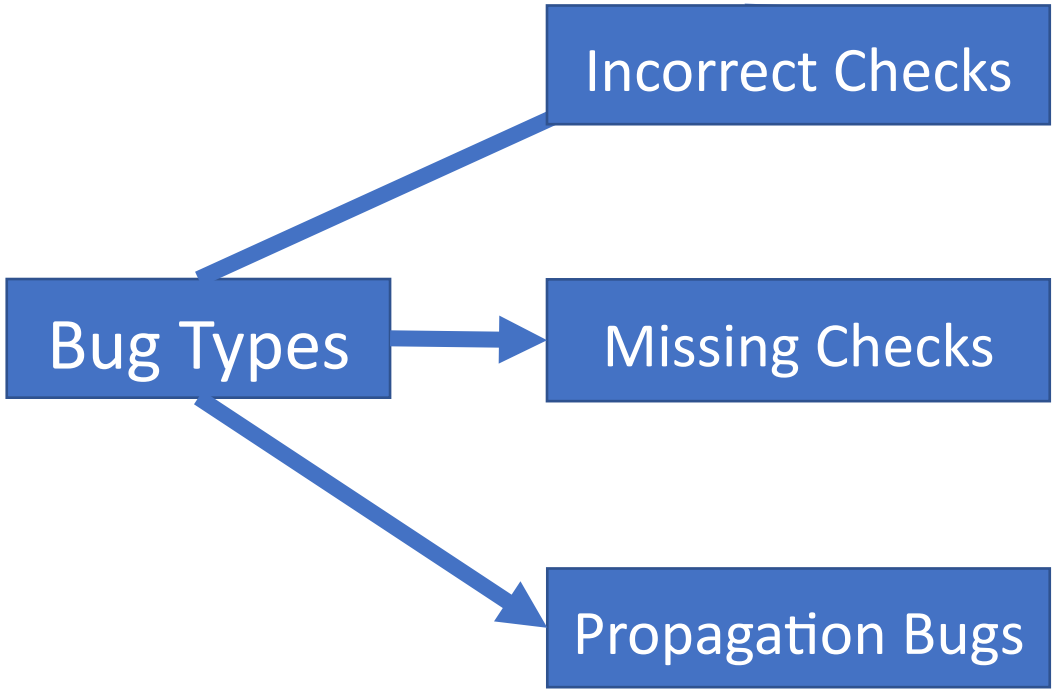


Error Check Bugs




```
if (generate_seed && RAND_bytes_ex(...) < 0)
  goto err;
```

Error Check Bugs




```
if (generate_seed && RAND_bytes_ex(...) < 0)
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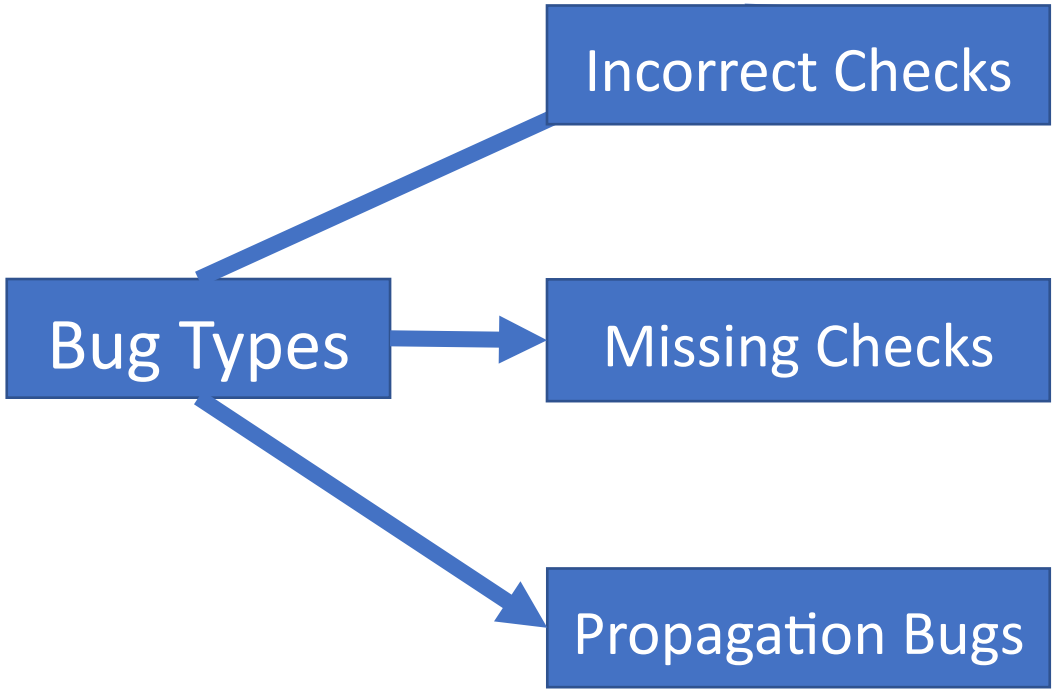
```

```
retval = xmlTextWriterStartElement(...);
if (retval == -1)
  return false;
xmlTextWriterEndElement(...);
if (retval == -1)
  return false;
```

Error Check Bugs

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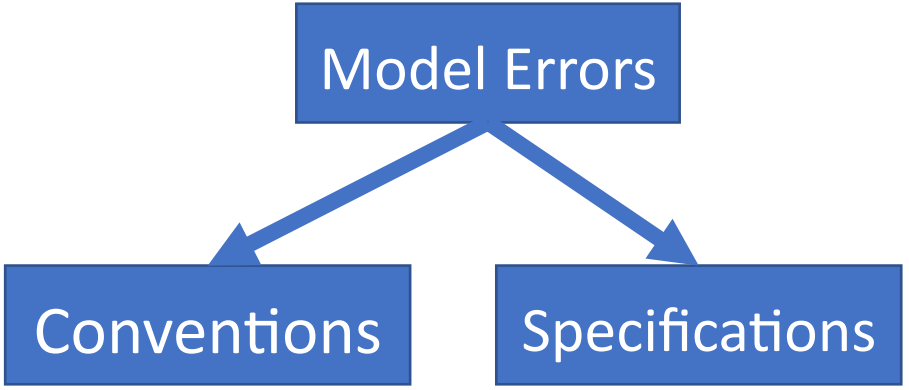
```

```
zend_result zend_update_static_property(...) {
  ...
  bool retval = zend_update_static_property_ex(...);
  ...
  return retval;
}
```

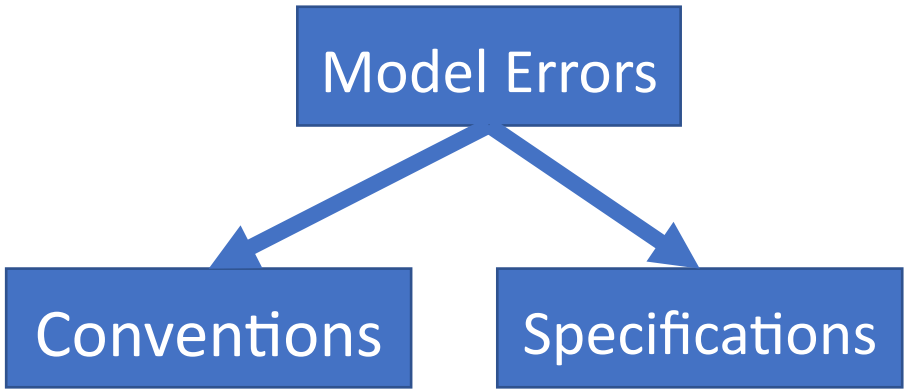
Static Approaches

Model Errors

Static Approaches

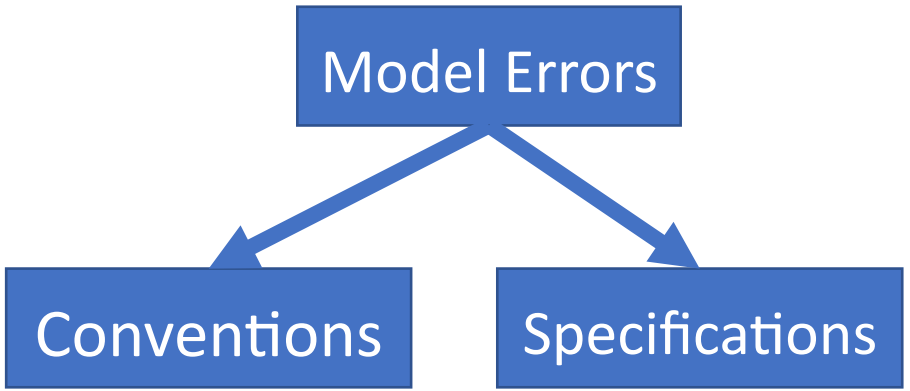


Static Approaches



e.g. NULL, EINVAL, goto error

Static Approaches



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malloc: {0}
open: {-1}
zend_get_property_info: {0} U {0xffff...}
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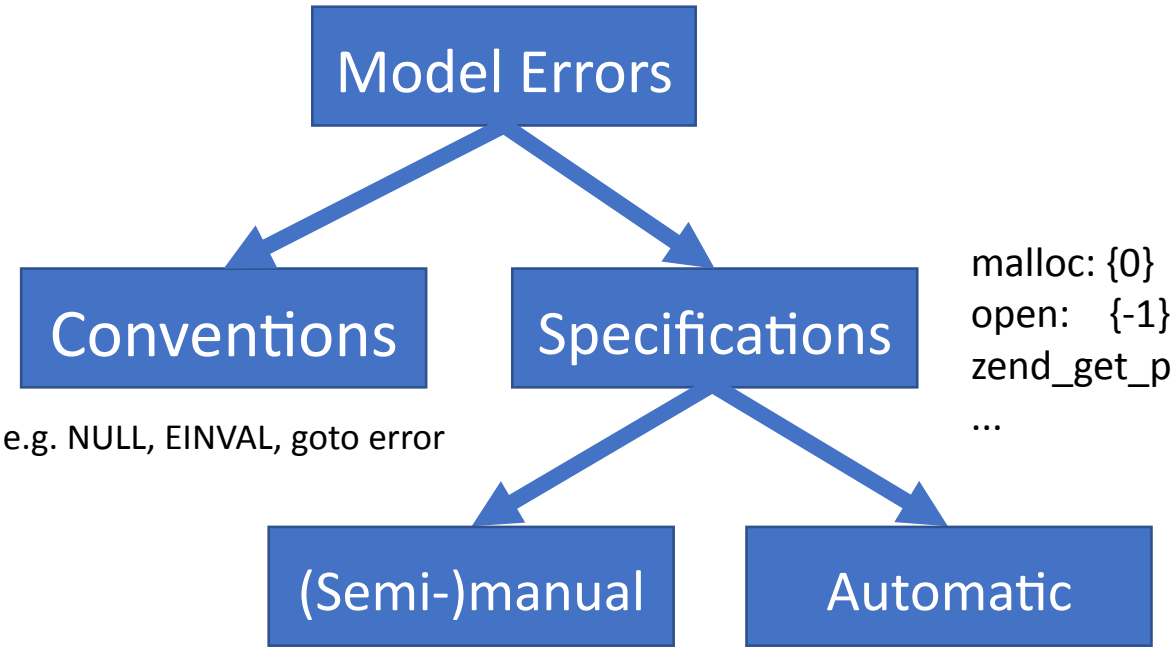

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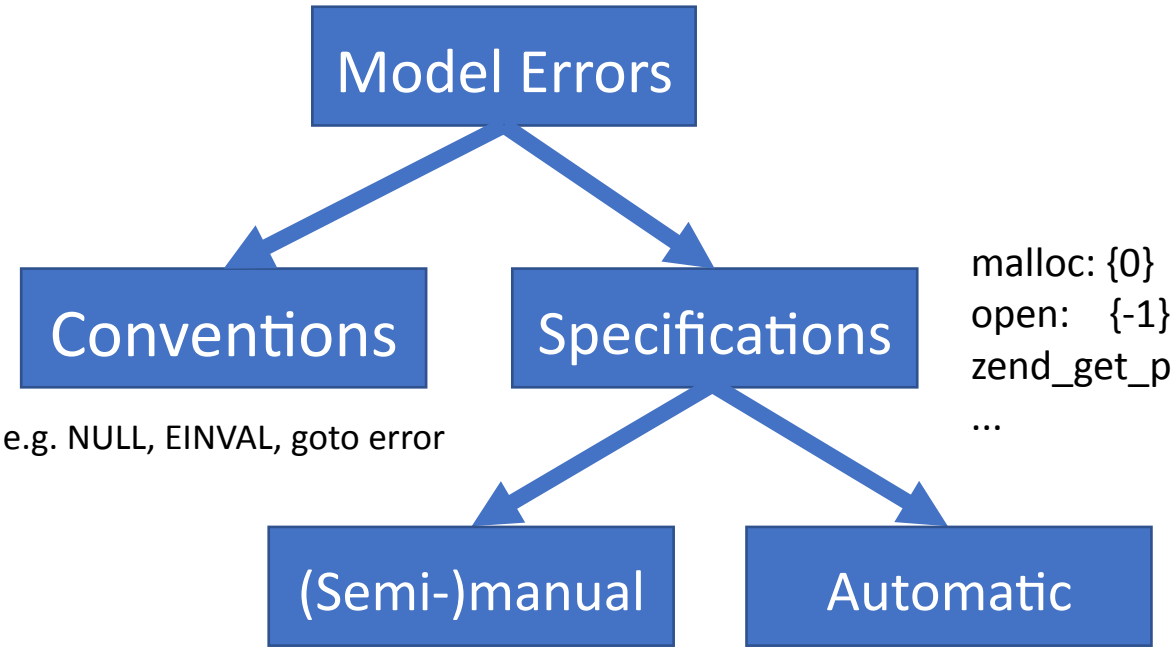

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e.g. EESI [1]

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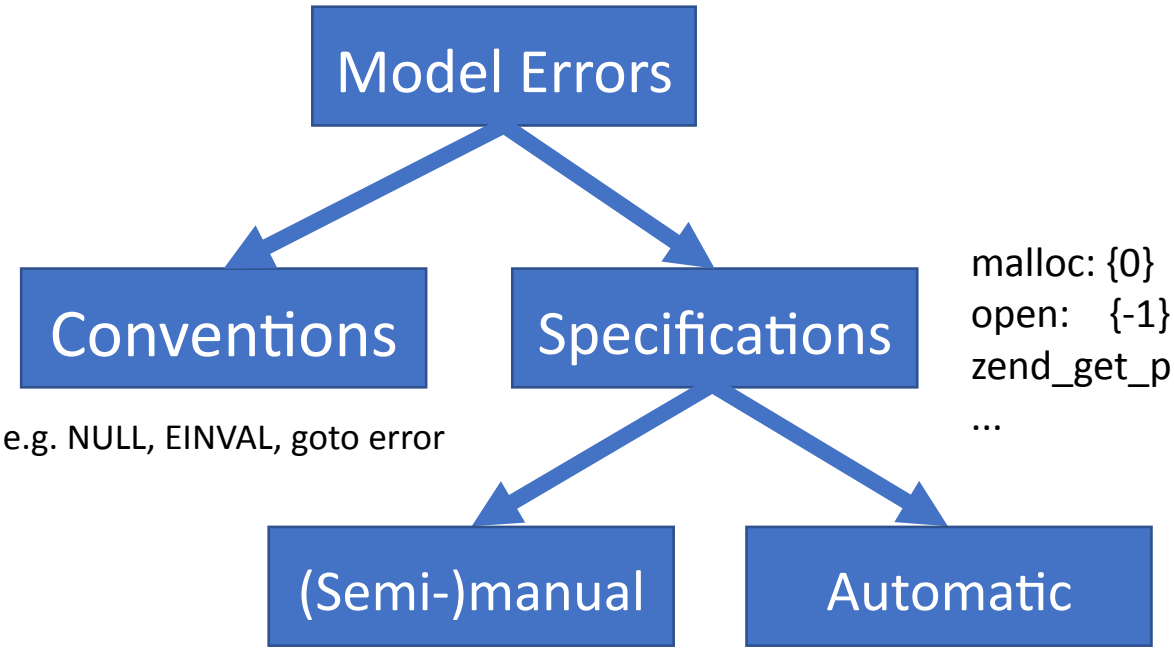

Convention-based Approach

```
int ossl_rsa_sp800_56b_check_keypair(...) {
  int ret = 0;
  if (!rsa_check_public_exponent(rsa->e)) {
    ERR_raise(ERR_LIB_RSA, RSA_R_PUB_EXPONENT_OUT_OF_RANGE);
    return 0;
  }
  BN_CTX *ctx = BN_CTX_new_ex(rsa->libctx);
  if (ctx == NULL)
    return 0;
  if (!BN_mul(...))
    goto err;
  ret = rsa_check_prime_factor(...) && rsa_check_crt_components(...);
  if (ret != 1)
    ERR_raise(ERR_LIB_RSA, RSA_R_INVALID_KEYPAIR);
err:
  BN_CTX_free(ctx);
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```

Source: OpenSSL 3.0

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Subsequence match of 2

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CALL BN_CTX_free
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→ Subsequence match of 2

Source: OpenSSL 3.0

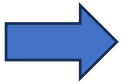
Expanding Error Specifications

```
int f() {
  int x = fallible();
  if (x != 0) {
    ERR_raise(...);
    return x;
  } else {
    return 0;
  }
}
```

Expanding Error Specifications

Single check

No similar code



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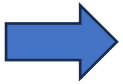

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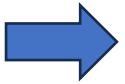

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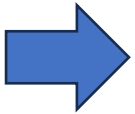

Association analysis

Expanding Error Specifications

```
int f() {
  void *x = malloc(...);
  if (x == NULL) {
    return -1;
  }
  ...
}
```

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malloc: {0}

Expanding Error Specifications

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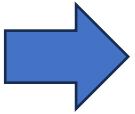


f == -1

Pipeline

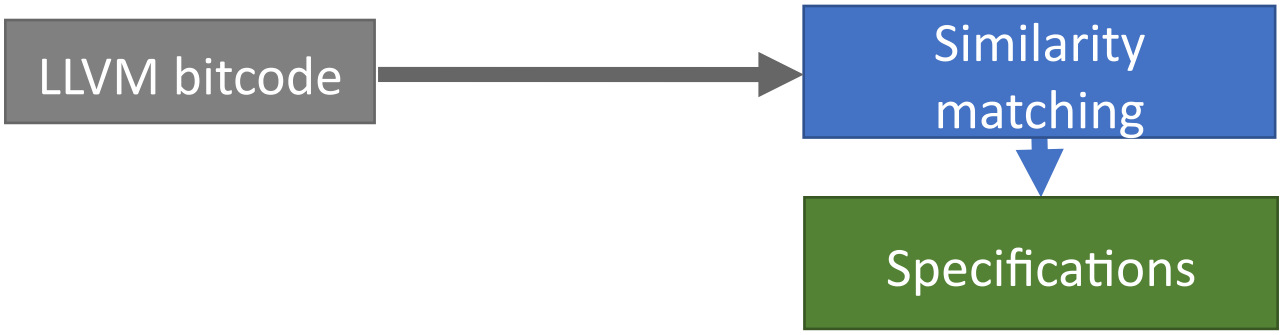
Pipeline

LLVM bitcode

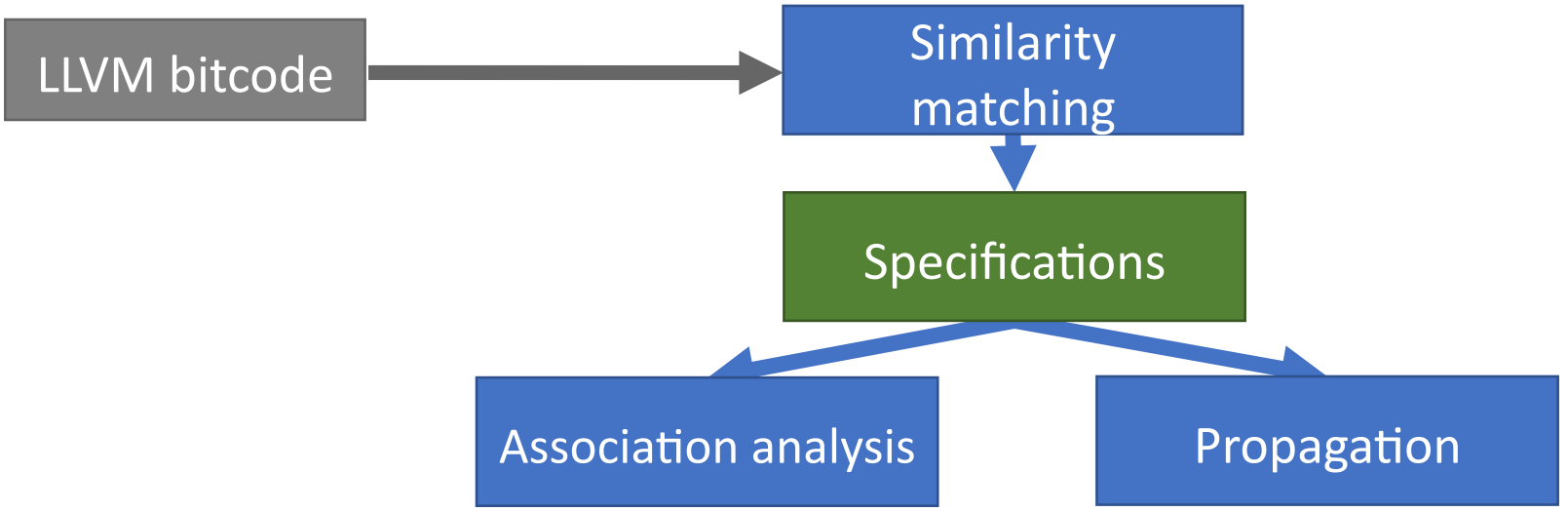
Pipeline

Pipeline

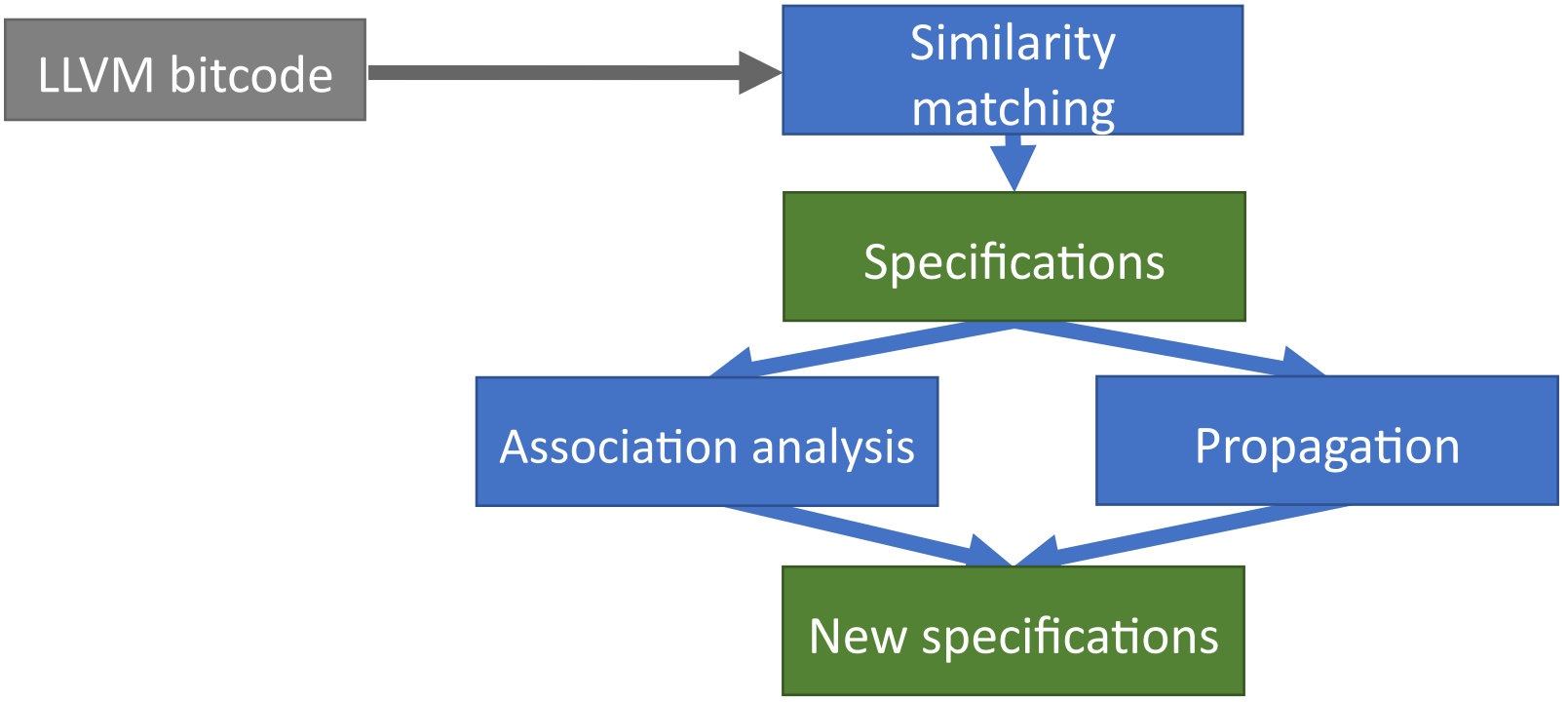
Pipeline



Pipeline


LLVM bitcode
Similarity matching
Specifications
Association analysis
Propagation

Pipeline


LLVM bitcode
Similarity matching
Specifications
Association analysis
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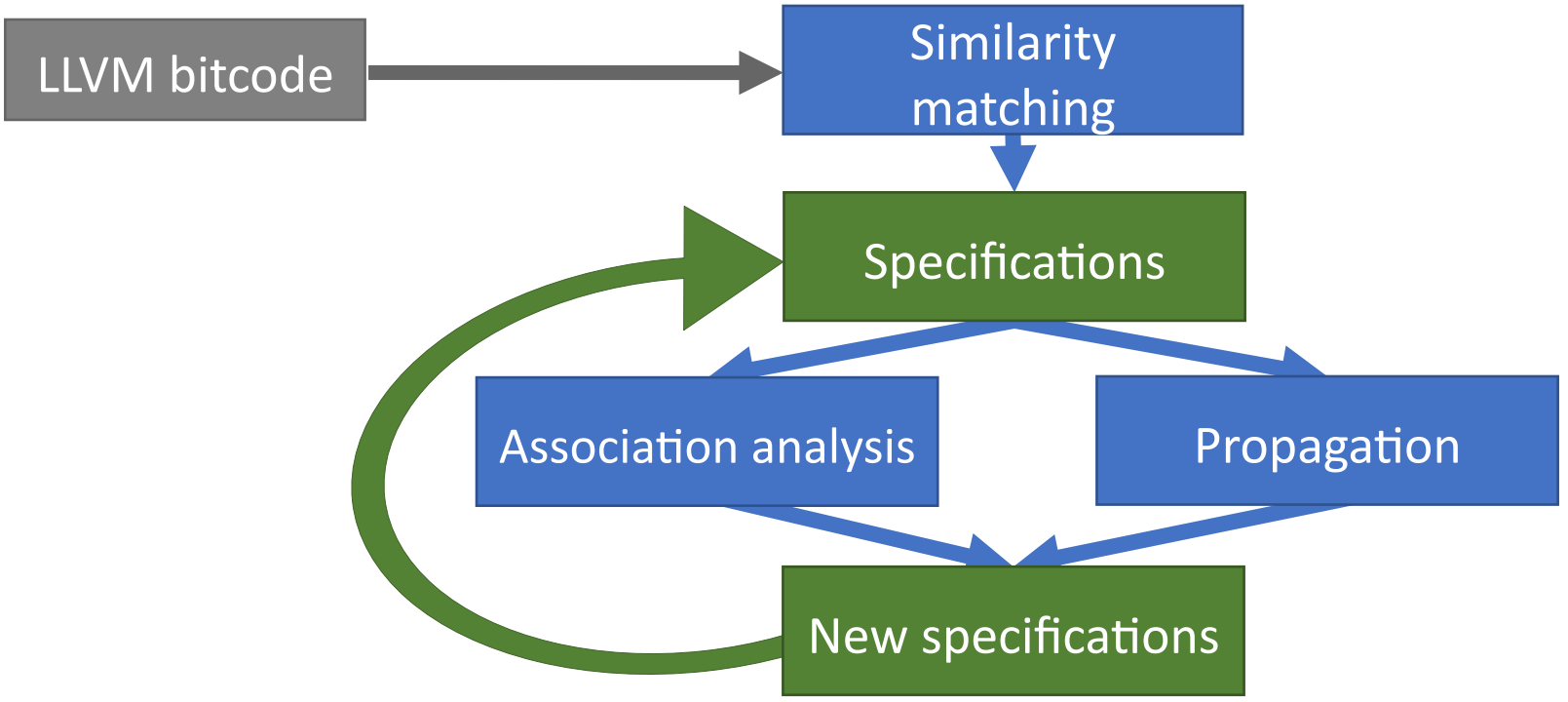
New specifications

Pipeline


LLVM bitcode
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Specifications
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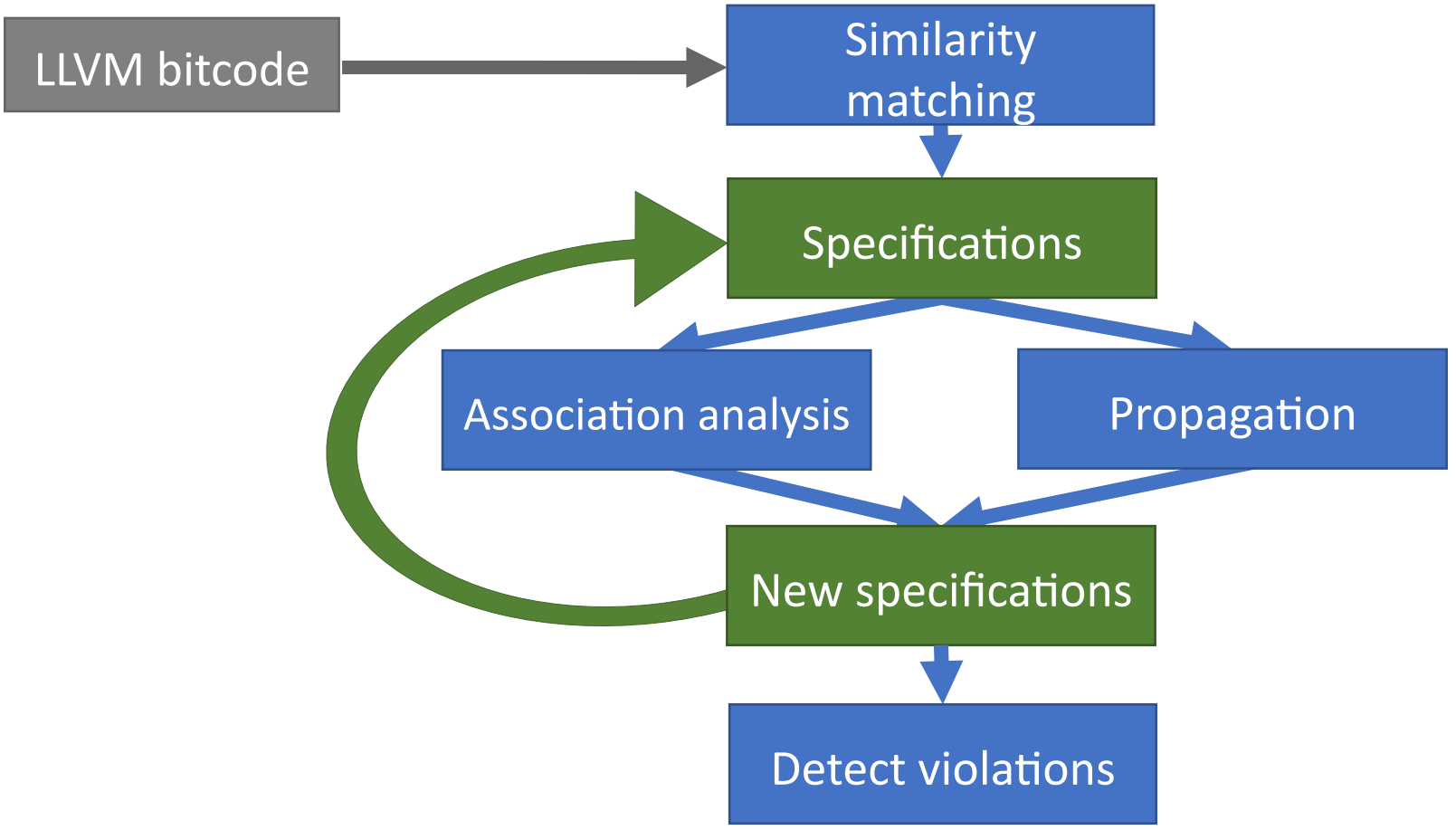
LLVM bitcode
Similarity matching
Specifications
Association analysis
Propagation
New specifications
Detect violations

Bug Report Results

Project	Reports	MC	IC	PB	Unknown	FPR MC	FPR IC	FPR total
OpenSSL								
OpenSSH								
PHP								
zlib								
libpng								
freetype2								
libwebp								

Bug Report Results

Project	Reports	MC	IC	PB	Unknown	FPR MC	FPR IC	FPR total
OpenSSL	366							
OpenSSH	61							
PHP	355							
zlib	4							
libpng	1							
freetype2	25							
libwebp	15							

Bug Report Results

Project	Reports	MC	IC	PB	Unknown	FPR MC	FPR IC	FPR total
OpenSSL	366	238	84	0				
OpenSSH	61	49	11	0				
PHP	355	303	29	3				
zlib	4	4	0	0				
libpng	1	1	0	0				
freetype2	25	20	4	0				
libwebp	15	13	0	0				

Bug Report Results

Project	Reports	MC	IC	PB	Unknown	FPR MC	FPR IC	FPR total
OpenSSL	366	238	84	0	44	46.22%	39.29%	44.41%
OpenSSH	61	49	11	0	1	16.33%	54.55%	23.33%
PHP	355	303	29	3	20	26.40%	44.83%	28.01%
zlib	4	4	0	0	0	25.00%	-	25.00%
libpng	1	1	0	0	0	0.00%	-	0.00%
freetype2	25	20	4	0	1	0.00%	50.00%	8.33%
libwebp	15	13	0	0	2	18.18%	-	18.18%

Inference Performance

Project	EESI		ESSS		SLOC
	Time	Memory	Time	Memory	
OpenSSL					
OpenSSH					
PHP					
zlib					
libpng					
freetype2					
libwebp					

Time in seconds, memory in GiB

Inference Performance

Project	EESI		ESSS		SLOC
	Time	Memory	Time	Memory	
OpenSSL	176.79	20.46			
OpenSSH	81.70	4.02			
PHP	-	-			
zlib	4.09	0.25			
libpng	21.44	4.50			
freetype2	91.66	10.56			
libwebp	12.65	2.20			

Time in seconds, memory in GiB

Inference Performance

Project	EESI		ESSS		SLOC
	Time	Memory	Time	Memory	
OpenSSL	176.79	20.46	3.22	0.75	542K
OpenSSH	81.70	4.02	1.44	0.22	120K
PHP	-	-	14.50	1.85	1.46M
zlib	4.09	0.25	0.38	0.05	30K
libpng	21.44	4.50	0.49	0.09	63K
freetype2	91.66	10.56	0.94	0.19	141K
libwebp	12.65	2.20	0.40	0.14	75K

Time in seconds, memory in GiB

Results

827 inspected bugs in 7 projects
541 true positives
46 fixed in 3 projects

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OpenSSL
Cryptography and SSL/TLS Toolkit

16 fixes

1 fix

php

29 fixes
(1 security bug)

And More!

- More experiments and details in paper
- Open-Source on GitHub: https://github.com/csl-ugent/ESSS
- Artifact evaluated

References

[1] Daniel DeFreez, Haaken Martinson Baldwin, Cindy Rubio-González, and Aditya V Thakur. Effective Error-Specification Inference via Domain-Knowledge Expansion. In Proceedings of the 2019 27th ACM Joint Meeting on European Software Engineering Conference and Symposium on the Foundations of Software Engineering

[2] Yuan Kang, Baishakhi Ray, and Suman Jana. APEx: Automated Inference of Error Specifications for C APIs. In Proceedings of the 31st IEEE/ACM International Conference on Automated Software Engineering

[3] Chi Li, Min Zhou, Zuxing Gu, Ming Gu, and Hongyu Zhang. Ares: Inferring Error Specifications through Static Analysis. In 2019 34th IEEE/ACM International Conference on Automated Software Engineering (ASE)

[4] Kangjie Lu and Hong Hu. Where Does It Go? Refining Indirect-Call Targets with Multi-Layer Type Analysis. In Proceedings of the 2019 ACM SIGSAC Conference on Computer and Communications Security