Validation of QBF Encodings with Winning Strategies

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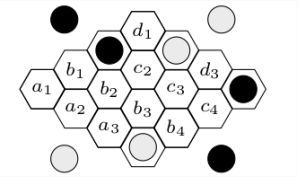
Validation Challenges

- Is the problem encoded correctly?
- Do encoding variations preserve correctness?

A case study: Hex encoding

Hein Puzzle 12



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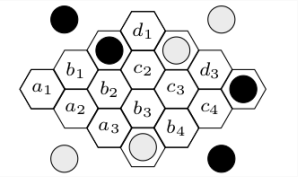

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$\exists \mathsf{M}^1 \forall \mathsf{M}^2 \ldots \exists \mathsf{M}^d$

$\exists \mathsf{W}_1, \ldots, \mathsf{W}_\mathsf{k}$

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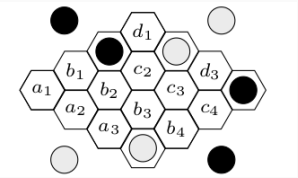

Encoding Variations

- LN : both players can only occupy empty cells

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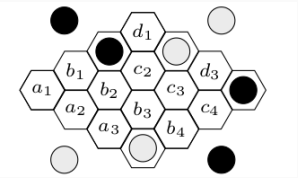

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- LN : both players can only occupy empty cells
- SN : black player can only occupy empty cells

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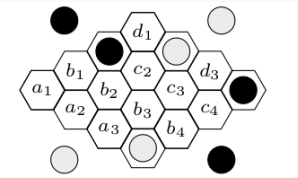

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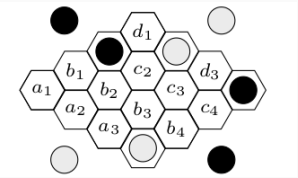

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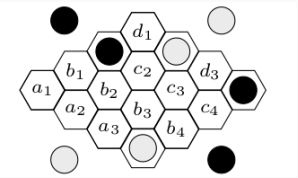

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- All QBF solvers provide outermost assignment.
- Extract inner variable assignments from modified QBFs

An Outline for Interactive Play

Pseudocode for True instance validation

1: **for** $i = 1;\ i < \max;\ i = i + 2$ **do**
2: Extract $\exists$-move
3: Input $\forall$-move
4: **end for**
5: Check the Assertion

$\exists\, M^1$

$\forall\, M^2$

$\exists\, M^3$

$\ldots$

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Expected Assertion Status for Encoding variations

Inst: / Assert:	GA	LBA
LN-Hein-12	✓	✓
SN-Hein-12	✓	✓
SN-R-Hein-12	✓	✗

Validation results from SQval

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	Static		Dynamic	
Instance: / Assertion:	GA	LBA	GA	LBA
LN-Hein-12	100/0	100/0	100/0	100/0
SN-Hein-12	100/0	100/0	100/0	100/0
SN-R-Hein-12	100/0	**91/9**	100/0	**84/16**

No of valid/invalid runs by SQval for Hein-12

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Equivalence Check of Similar Encodings

Equivalence Check of Encodings with Common Winning Strategies

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- Check if the new formula $\phi_2 \wedge S_2$ is also True.
- If False, the encodings are not equivalent.

Results on Equivalence Check for Hein-12

Subsumption (Q1 $\sqsubseteq$ Q2) test results from SQval

Q1: / Q2:	LN	SN	SN-R
LN	T	T	T
SN	T	T	T
SN-R	**F**	**F**	T

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- SN-R allows overwriting black moves, whereas LN and SN does not.

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- SN-R allows overwriting black moves, whereas LN and SN does not.
- Each subsumption checks take a few seconds at most.

Scaling Validation

Scalable Validation with Partial Certificates

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- Each validation iteration needs to solve a QBF instance

Scalable Validation with Partial Certificates

Static Validation + Dynamic Validation : Hybrid

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- Using partial certificates for first k layers, usually k $= 3$ is enough
- For rest of the layers, we interactively play with a QBF solver
- Partial certificates are orders of magnitude more compact.
- Solving QBF formulas with fewer quantifiers is several orders faster.

Validating Hein-09 with Partial Certificates

A Hein-09 instance:

- open positions : 10
- moves : 9
- solving time : 1203 seconds
- certificate size : 7.8GB

Validating Hein-09 with Partial Certificates

Certificate sizes for Hein-09 instances

		Partial Certificate				
Instance	Full Certificate	k=1	k=3	k=5	k=7	k=9
LN-Hein-09	7.8G	108	1.1K	21.8K	434K	8.2M
SN-Hein-09	641.6M	96	1.1K	23.4K	437.3K	8.2M
SN-R-Hein-09	532.7M	96	1.2K	24.2K	461.1K	8.7M

Size in Bytes

Validating Goal Assertion (GA)

	static		dynamic		hybrid-L3	
Instance	PM	TT	PM	TT	PM	TT
LN-Hein-09	-	TO	64.1	1203	**1.54**	**1.6**
SN-Hein-09	20.08K	2100	1.54	9.4	**1.53**	**0.4**
SN-R-Hein-09	18.35K	1226	**1.53**	5.4	**1.53**	**0.4**

Peak Memory (PM) in MB and Time Taken (TT) in seconds

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	LN-Hein-09		SN-Hein-09		SN-R-Hein-09	
Inst:	Full	L9	Full	L9	Full	L9
LN-Hein-09	-	1.53	-	1.57	-	1.57
SN-Hein-09	63.7	1.53	63.7	1.6	63.7	1.6
SN-R-Hein-09	50.74	1.6	50.78	1.6	50.8	1.69

Peak Memory for subsumption check in GB

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- Partial certificates for scaling validation

SQval

Future Work

- Partial traces from QBF solver would help for scalable validation

Conclusion

Summary

- Validation using interactive play + assertions
  - Static : using Skolem/Herbrand functions
  - Dynamic : using QBF solver
- Equivalence checks with common winning strategies
- Partial certificates for scaling validation

SQval

Future Work

- Partial traces from QBF solver would help for scalable validation
- Allowing subsumption check beyond encodings with common variables