Scalable Redundancy Detection for Real Time Requirements

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September 5, 2024

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- Either way, *they have to be known*.

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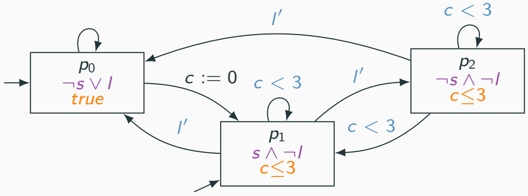
$$\neg \exists \pi \bullet \mathcal{P}(\mathcal{A}_0, \ldots, \overline{\mathcal{A}_j}, \ldots, \mathcal{A}_n) \ni \pi$$

Complementing Phase Event Automata

$\mathtt{r}_1$: If *sensor* holds, then *light* holds after at most 3 time units.



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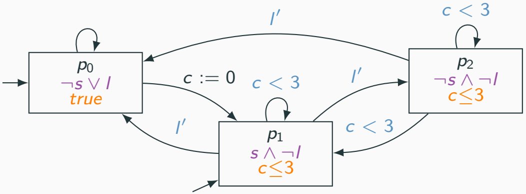

run: sequence of configurations: $(p_0, \beta_0, \gamma_0, t_0), \ldots, (p_n, \beta_n, \gamma_n, t_n)$

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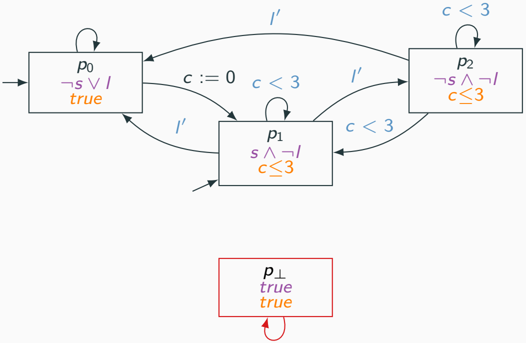

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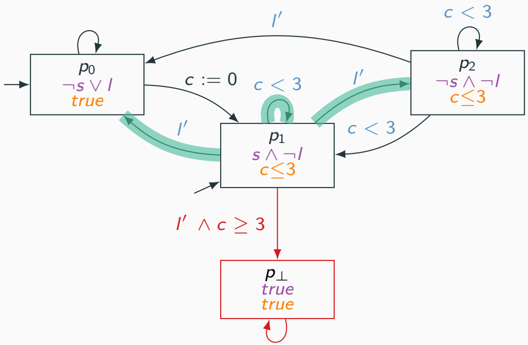

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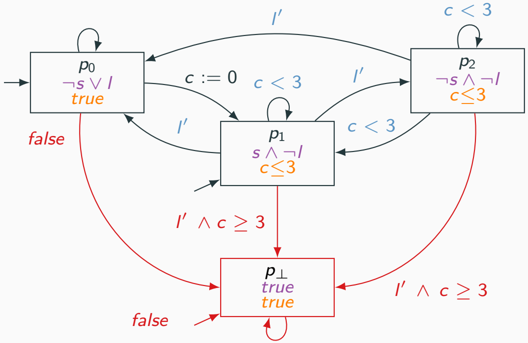

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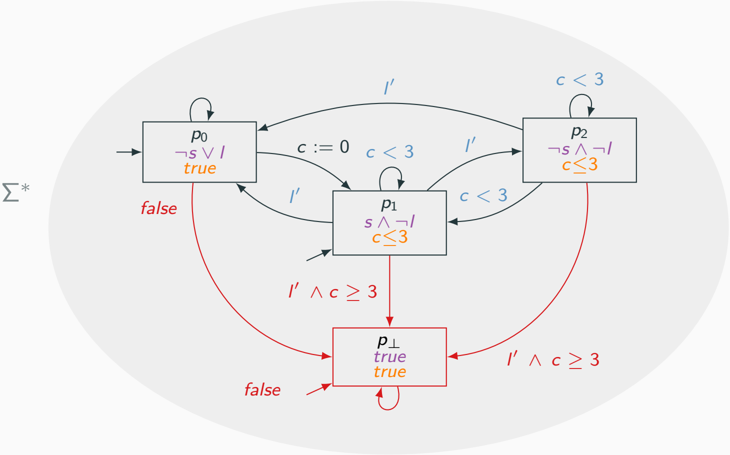

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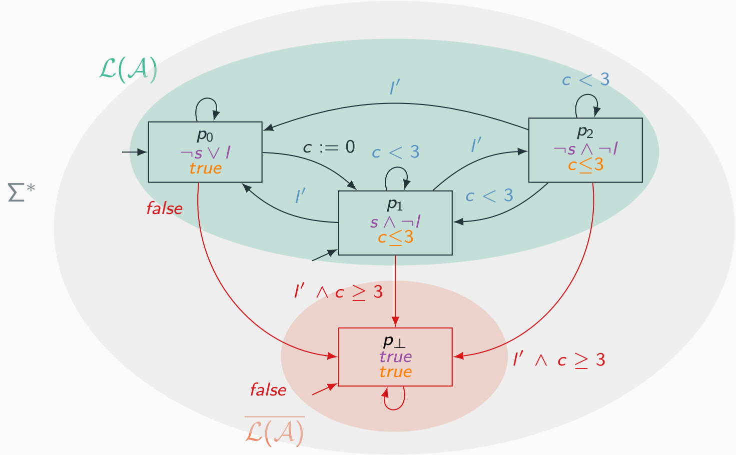

Encoding Redundancy as a Program Analysis Task

- Instead of encoding $\mathcal{P}(\mathcal{A}_0, .., \overline{\mathcal{A}_j}, ..., \mathcal{A}_n)$ for each $\mathtt{r}_j$, we encode $\mathcal{P}_{red} = \mathcal{P}(\mathcal{A}^t_0, .., \mathcal{A}^t_j, ..., \mathcal{A}^t_n)$ only once.
- $\mathcal{P}_{red}$ simulates the execution of $\mathcal{A}_{red} = \mathcal{A}^t_0 || ... || \mathcal{A}^t_j || ... || \mathcal{A}^t_n$.
- A run in $\mathcal{A}_{red}$ that contains a configuration $((p_0, ..., p_j, ..., p_n), \beta, \gamma, t)$, where $p_j = p^j_\perp$, while $p_i \neq p^i_\perp$ for all $i \neq j$, represents system behaviour that violates $\mathtt{r}_j$, but is not prohibited by the rest.
- For each requirement $\mathtt{r}_j$: introduce an error location l^j_{err} to $\mathcal{P}_{red}$ with an annotation expressing the above.

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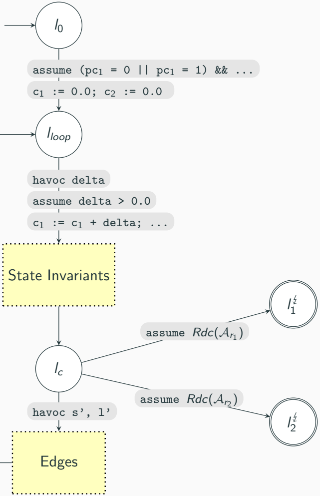
- A run in $\mathcal{A}_{red}$ that contains a configuration $((p_0, ..., p_j, ..., p_n), \beta, \gamma, t)$, where $p_j = p_\perp^j$, while $p_i \neq p_\perp^i$ for all $i \neq j$, represents system behaviour that violates $\mathtt{r}_j$, but is not prohibited by the rest.
- For each requirement $\mathtt{r}_j$: introduce an error location l_{err}^j to $\mathcal{P}_{red}$ with an annotation expressing the above.

l_{err}^j is reachable if and only if the requirement is not redundant.
l_{err}^j is not reachable if and only if the requirement is redundant

Toy Example

$\mathtt{r}_1$: If *sensor* holds, then *light* holds after at most 3 time units.
$\mathtt{r}_2$: If *sensor* holds, then *light* holds after at most 5 time units.

Resulting Boogie Program (for our toy example)



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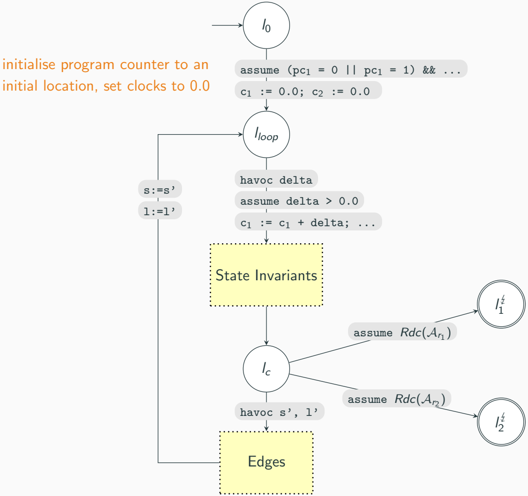

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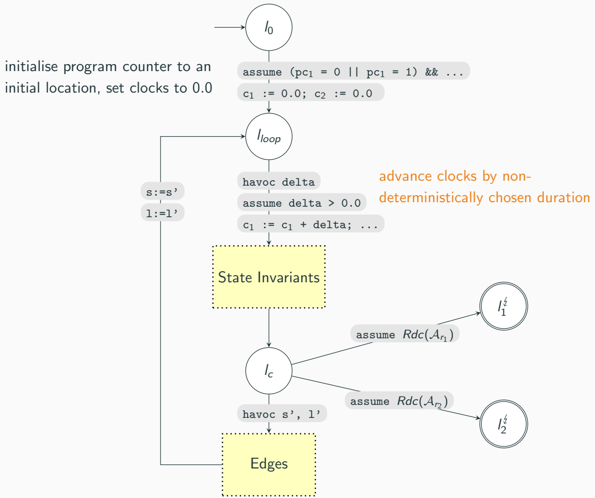

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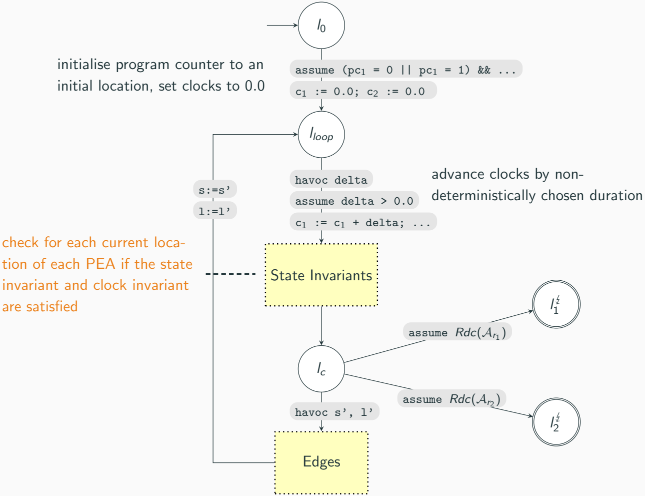

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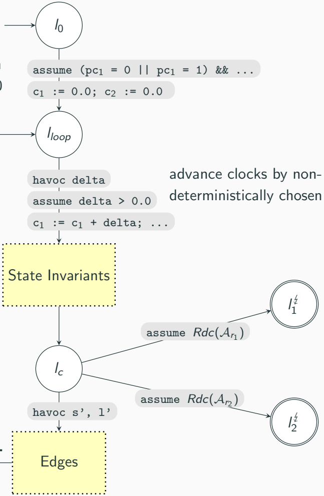

initialise program counter to an initial location, set clocks to 0.0

advance clocks by non-deterministically chosen duration

check for each current location of each PEA if the state invariant and clock invariant are satisfied

check if transitions can be taken, change program counter accordingly

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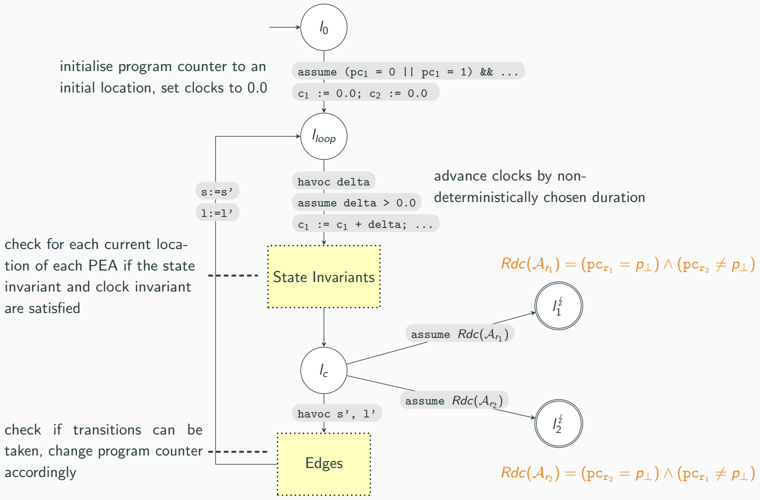

Evaluation

	Requirements			Redundancy			
ID	R	RT	V	No	Yes	TO	T (min)
dev-01	26	21	27	26	0	0	0.7
dev-02	50	47	53	49	1	0	5.8
dev-03	52	11	34	51	0	1	15.9
dev-04	58	53	53	57	1	0	7.2
dev-05	68	64	89	64	2	2	39.7
abz	83	52	52	78	5	0	23.3
dev-06	100	95	101	99	0	1	21.6
dev-07	107	80	172	107	0	0	3.5
dev-08	263	234	239	235	7	21	375.5
dev-09	407	358	326	396	4	7	464.1
dev-10	699	543	1003	684	7	8	819.2

- Implemented as part of Ultimate ReqAnalyzer
- 15 min timeout per requirement; AMD Ryzen 5 5600 6-Core CPU with 3.5 GHz and 30 GB RAM

Conclusion

Recap

- Classical approach to redundancy
- Encoded as program analysis task
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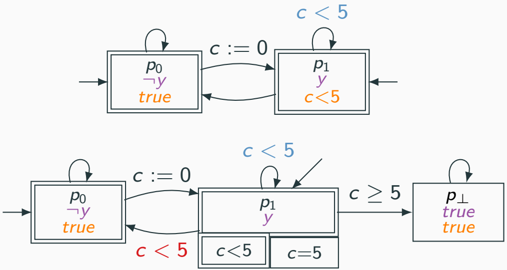
Future Work

- Extract explanations to support interpretation of redundancy analysis results
- Minimisation of Phase Event Automata
- Upcoming journal submission: Redundancy vs. Vacuity

Formalization

Strict Clock Invariants



Deep Dive

Non-sink transitions of the totalized PEA:

$$E^t(p) := \begin{cases} E(p) & \text{if } I(p) = I^t(p), \\ \{(p, g^t, X, p') \mid (p, g, X, p') \in E \wedge g^t = (g \wedge \bigwedge_{(c_i < t_i) \in I(p)} c_i < t_i)\} & \text{otherwise.} \end{cases}$$

Guards for the sink transitions:

$$g_\perp(p) := p_\perp \neg \bigvee_{(p,g,X,p') \in E^t} \left(g \wedge s'(p') \wedge \bigwedge_{\{\delta_c \mid \delta_c \in I_<(p') \wedge c \notin X\}} \delta_c \right)$$

$$g_\perp^{in} := \neg \bigvee_{(g,p) \in E_0} (g \wedge s'(p))$$

Sink transitions of the totalized PEA:

$$E_\perp := \bigcup_{p \in P} (p, g_\perp(p), \emptyset, p_\perp) \cup \{(p_\perp, true, \emptyset, p_\perp)\}$$