Formal Verification of Networks
—Description Language—

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Australian Government
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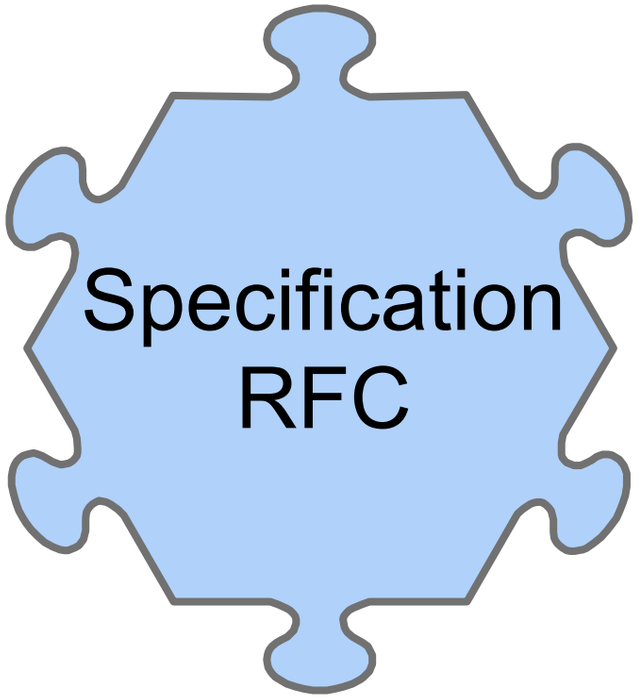
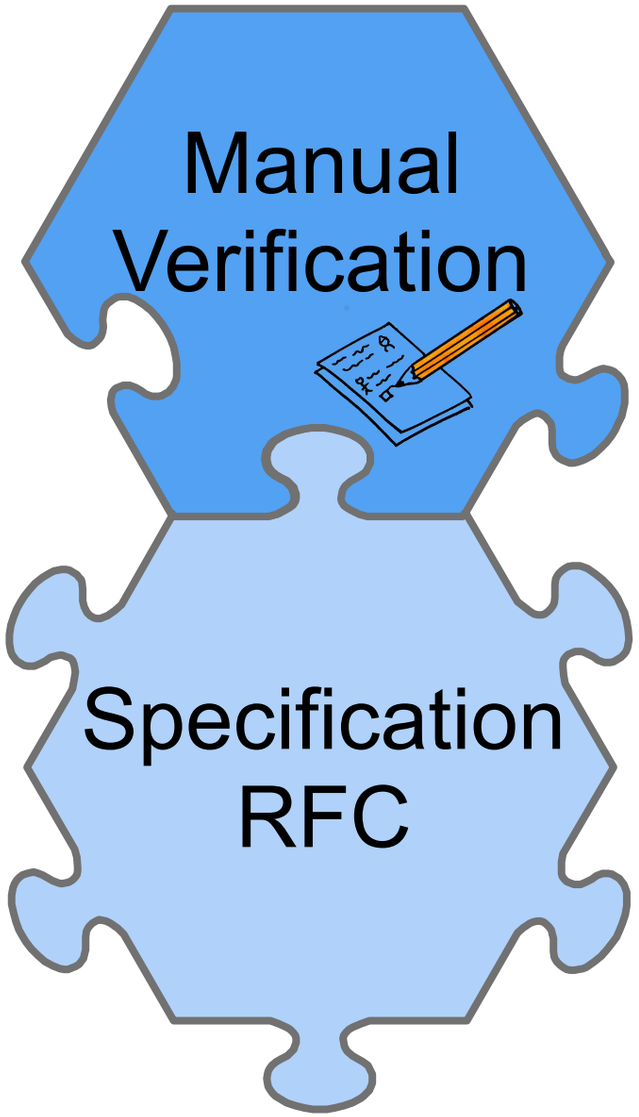
The Big Picture

The Big Picture



The Big Picture



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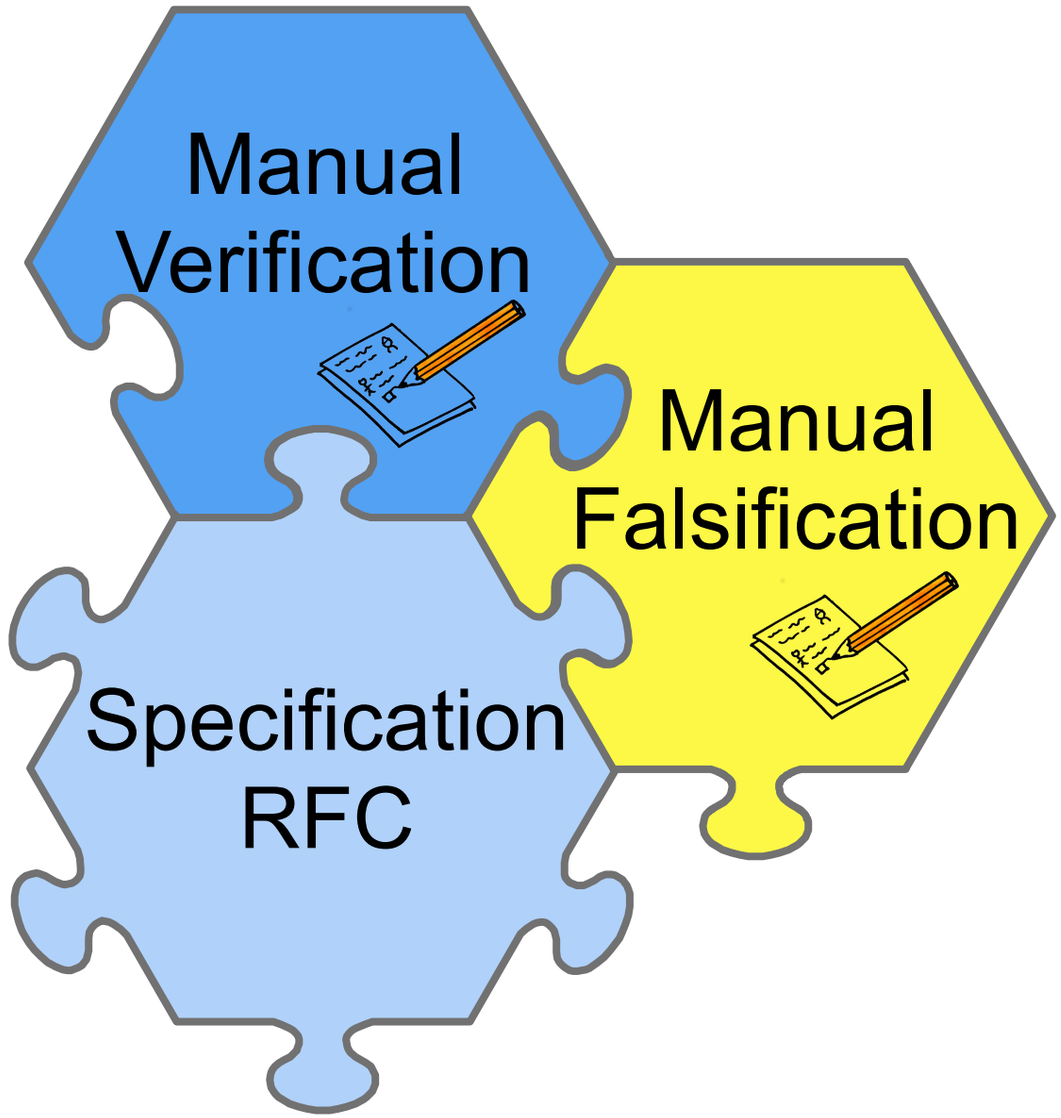

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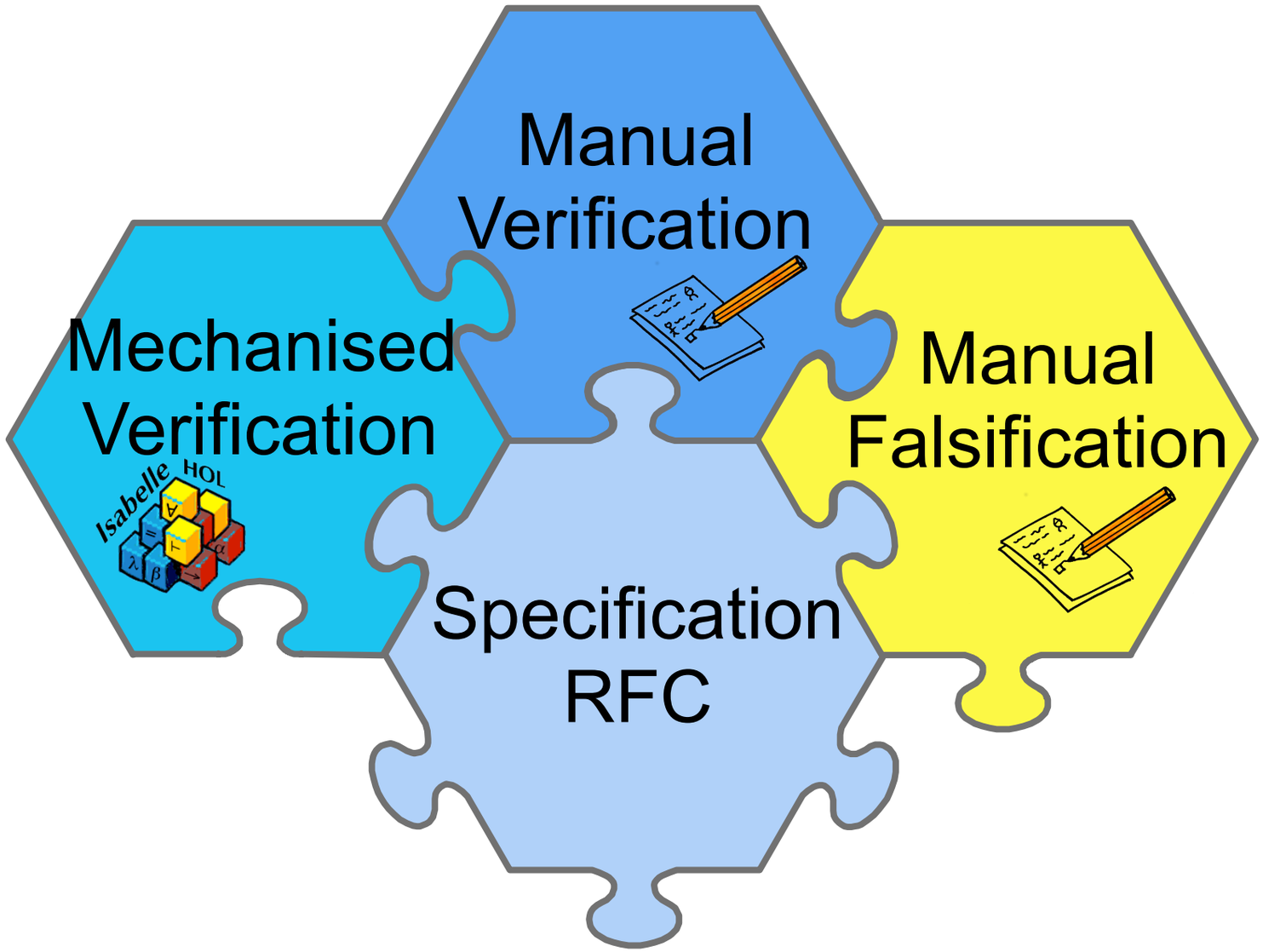

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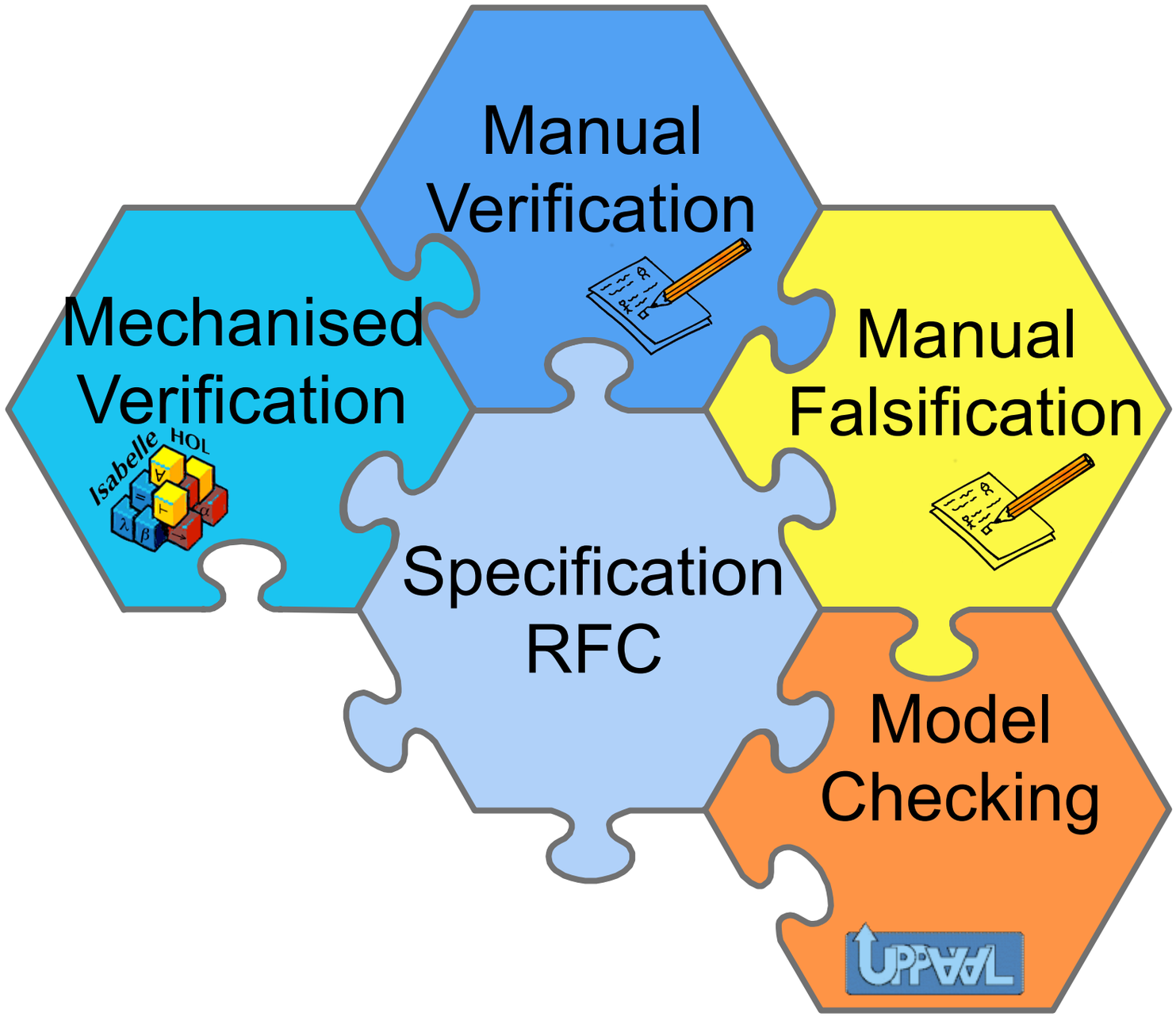

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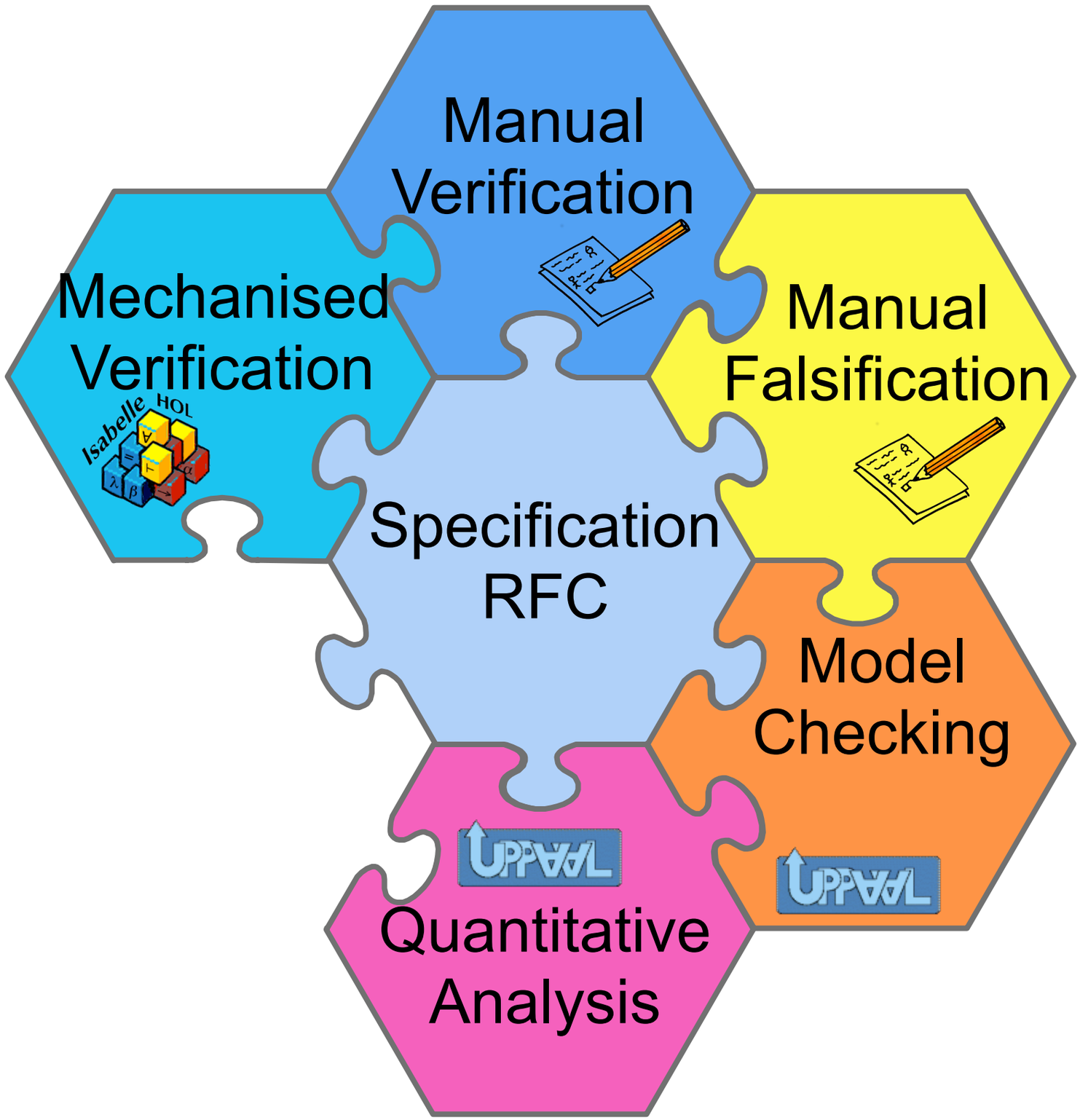

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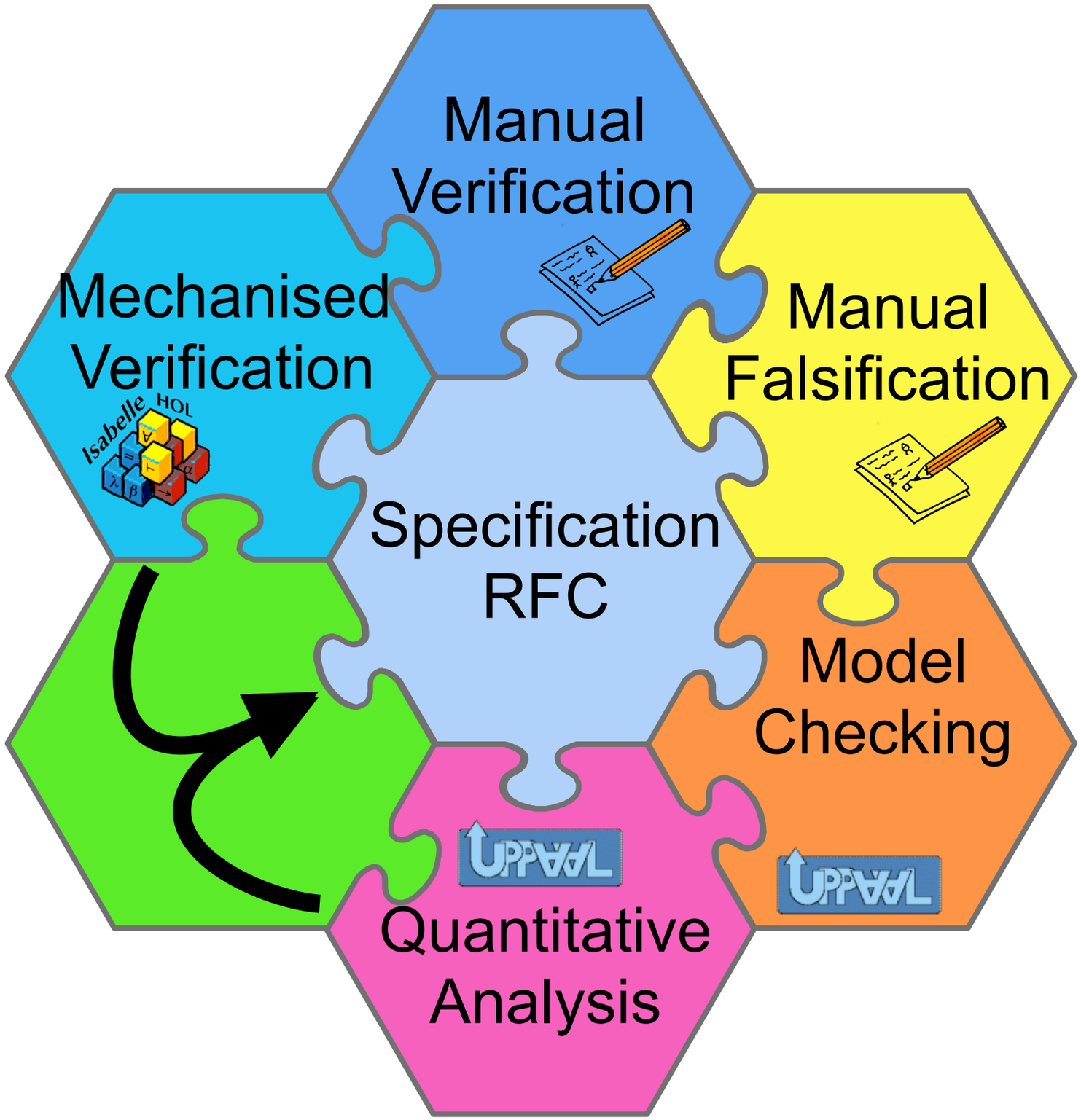
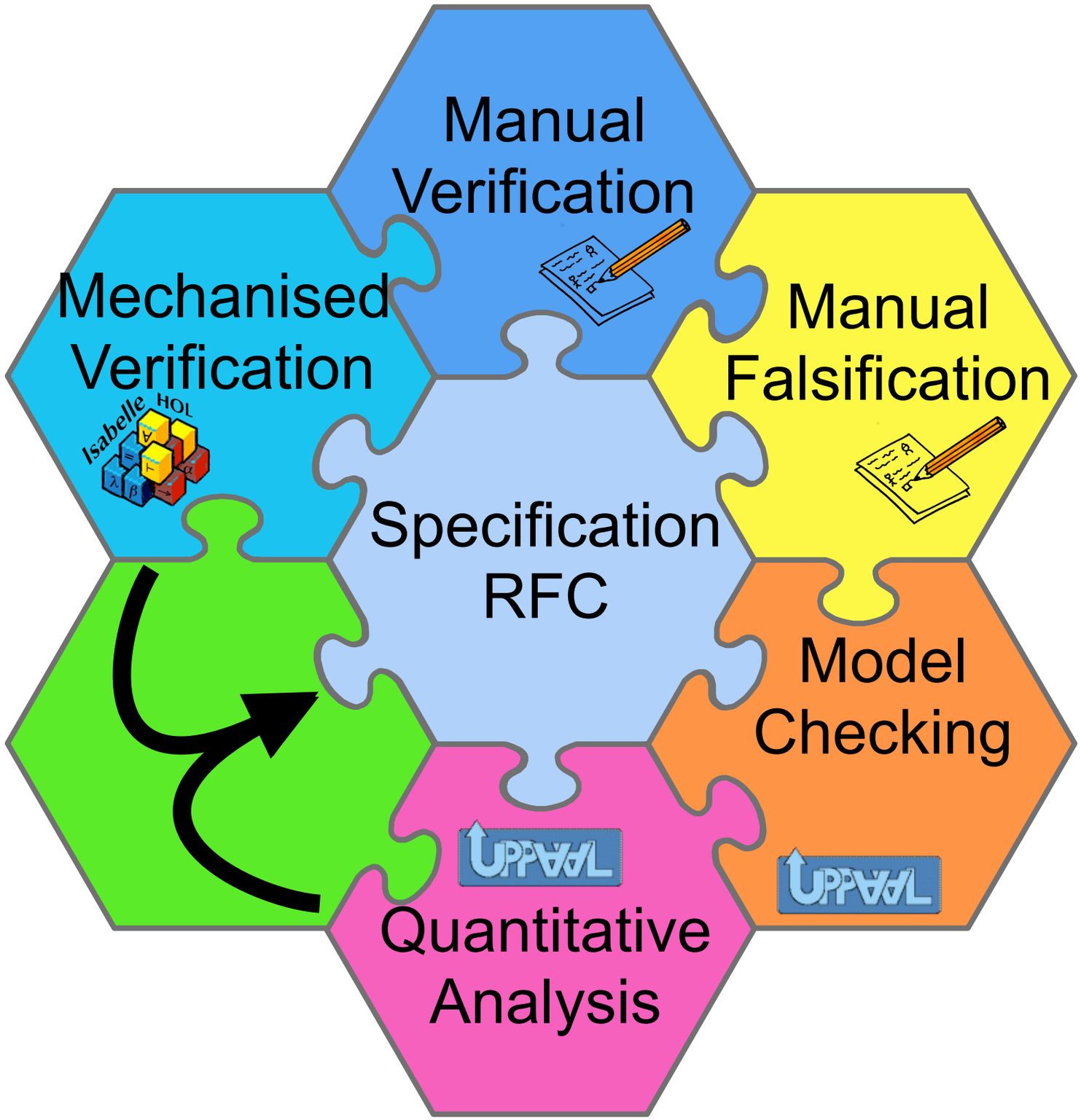


Motivation (Current Problems)

- specifications are not precise
  - written in English
  - ambiguous (sometimes incomplete)
- compliant implementations
  - have different behaviours
  - are not compatible
  - have serious flaws
- traditional evaluation techniques: simulation and test-bed
  - expensive
  - limited to (a small number of) specific scenarios
  - error found after years of evaluation
  - barely offer any guarantee for properties

The Big Picture



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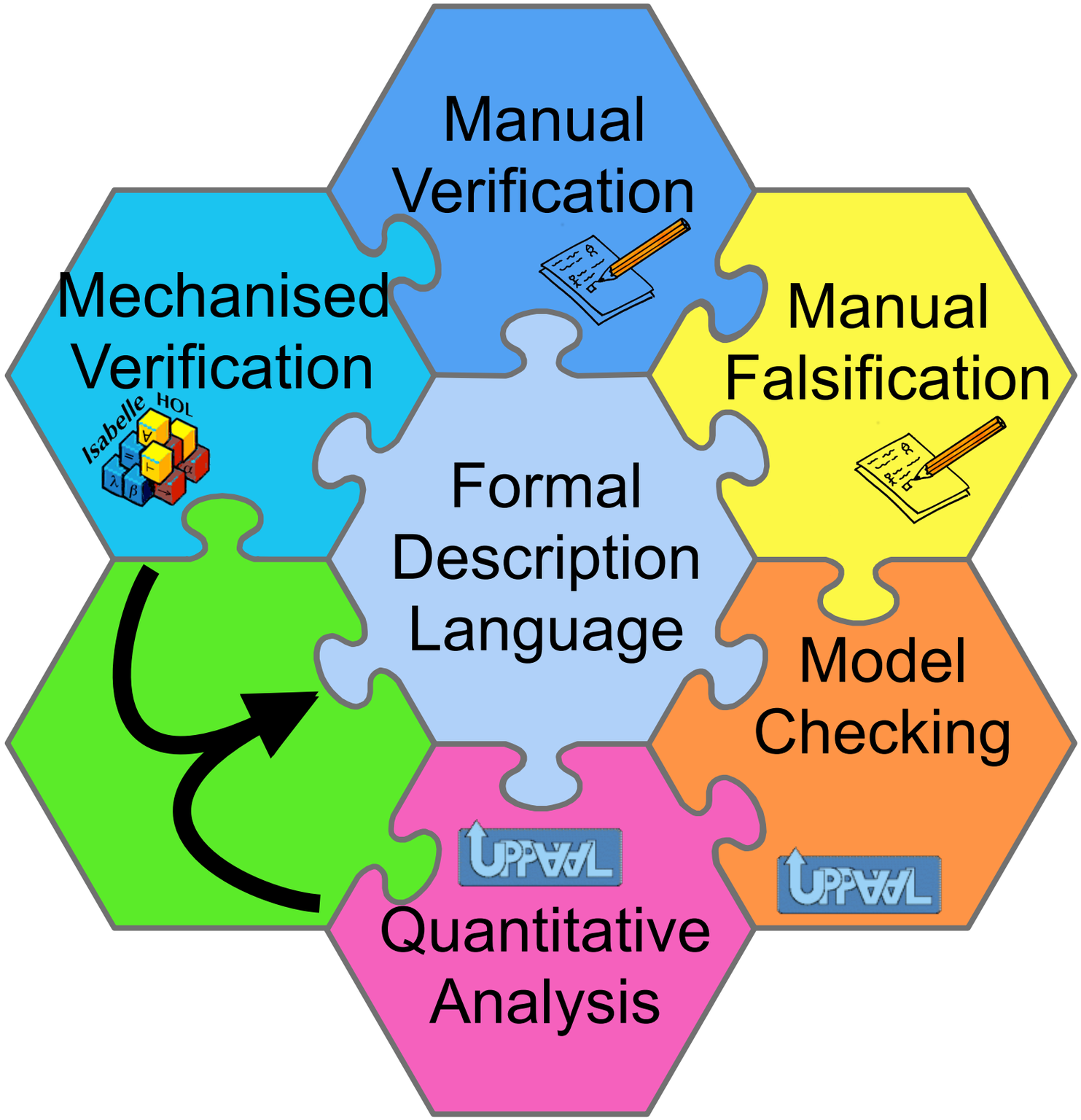

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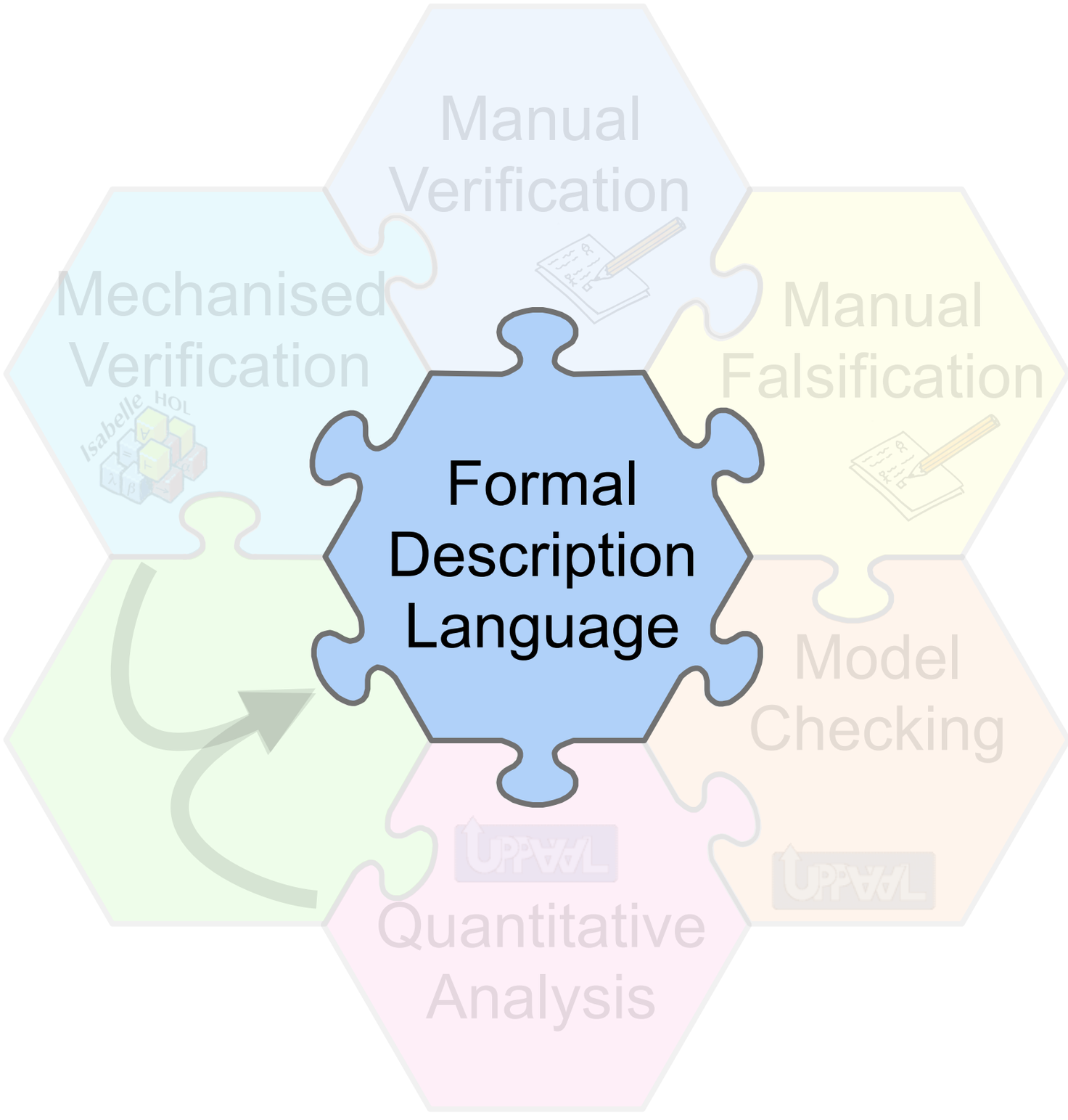

Requirements for Formal Languages

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- "Formal languages are useful tools for specifying parts of protocols. However, as of today, there exists no well-known language that is able to capture the full syntax and semantics of reasonably rich IETF protocols." [IETF]

- IETF Requirements (for formal methods)
  - relatively easy to extract code
  - complete specification
  - implementation independent
- Additional Requirement
  - easy to use

Desired Constructs

- message sending
  - broadcast
  - unicast
  - groupcast
- data
  - (arbitrary) structures
  - assignments
- operations
  - sequential process
  - choice
  - guards
  - parallelism

Structure of Networks

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- user (encapsulation)
  - Network as a “cloud”
- collection of nodes
  - connect / disconnect / send / receive
  - “parallel execution” of nodes
- nodes
  - data management
    - data packets, messages, IP addresses ...
  - message management (avoid blocking)
  - core management
    - broadcast / unicast / groupcast ...
  - “parallel execution” of sequential processes

Description Language (Nodes)

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$X(exp_1, \ldots, \exp_n)$	process calls
$P + Q$	nondeterministic choice
$[\varphi]P$	if-construct (guard)
$[\![\texttt{var} := exp]\!]P$	assignment followed by
$\mathbf{broadcast}(ms).P$	broadcast
$\mathbf{groupcast}(dests, ms).P$	groupcast
$\mathbf{unicast}(dest, ms).P \blacktriangleright Q$	unicast
$\mathbf{send}(ms).P$	send
$\mathbf{receive}(\texttt{msg}).P$	receive
$\mathbf{deliver}(data).P$	deliver

Structural Operational Semantics I

- beyond description language
  - internal state determined by expression and valuation

$$\xi, \mathbf{broadcast}(ms).p \xrightarrow{\mathbf{broadcast}(\xi(ms))} \xi, p$$

$$\xi, \mathbf{groupcast}(dests, ms).p \xrightarrow{\mathbf{groupcast}(\xi(dests),\xi(ms))} \xi, p$$

$$\xi, \mathbf{unicast}(dest, ms).p \blacktriangleright q \xrightarrow{\mathbf{unicast}(\xi(dest),\xi(ms))} \xi, p$$

$$\xi, \mathbf{unicast}(dest, ms).p \blacktriangleright q \xrightarrow{\neg\mathbf{unicast}(\xi(dest))} \xi, q$$

$$\xi, \mathbf{send}(ms).p \xrightarrow{\mathbf{send}(\xi(ms))} \xi, p$$

$$\xi, \mathbf{deliver}(data).p \xrightarrow{\mathbf{deliver}(\xi(data))} \xi, p$$

$$\xi, \mathbf{receive}(\mathtt{msg}).p \xrightarrow{\mathbf{receive}(m)} \xi[\mathtt{msg} := m], p \qquad (\forall m \in \mathtt{MSG})$$

Description Language (2)

$P \lll Q$	parallel operator on nodes

- Do we need more?

$[\varphi]P + [\neg\varphi]Q$	deterministic choice
$P(n) = [\![n := n + 1]\!].P(n)$	loops

Collection of Nodes and Encapsulation

- Node expressions: $M ::= \quad ip : P : R \quad | \quad M \| M$
- Encapsulation: $\mathrm{N} ::= [\mathrm{M}]$

- SOS rules more or less straight-forward

Case Study: AODV

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$+$ [$(\texttt{oip},\texttt{rreqid}) \notin \texttt{rreqs}$] /* the RREQ is new to this node */
⟦$\texttt{rt} := \texttt{update}(\texttt{rt},(\texttt{oip},\texttt{osn},\texttt{kno},\texttt{val},\texttt{hops}+1,\texttt{sip},\emptyset))$⟧ /* update the route to oip in rt */
⟦$\texttt{rreqs} := \texttt{rreqs} \cup \{(\texttt{oip},\texttt{rreqid})\}$⟧ /* update rreqs by adding (oip, rreqid) */
(
[$\texttt{dip} = \texttt{ip}$] /* this node is the destination node */
⟦$\texttt{sn} := \max(\texttt{sn},\texttt{dsn})$⟧ /* update the sqn of ip */
/* unicast a RREP towards oip of the RREQ */
unicast(nhop(rt,oip),rrep(0,dip,sn,oip,ip)) . AODV(ip,sn,rt,rreqs,store)
▶ /* If the transmission is unsuccessful, a RERR message is generated */
⟦$\texttt{dests} := \{(\texttt{rip},\texttt{inc}(\texttt{sqn}(\texttt{rt},\texttt{rip}))) \mid \texttt{rip} \in \texttt{vD}(\texttt{rt}) \wedge \texttt{nhop}(\texttt{rt},\texttt{rip}) = \texttt{nhop}(\texttt{rt},\texttt{oip})\}$⟧
⟦$\texttt{rt} := \texttt{invalidate}(\texttt{rt},\texttt{dests})$⟧
⟦$\texttt{store} := \texttt{setRRF}(\texttt{store},\texttt{dests})$⟧
⟦$\texttt{pre} := \bigcup\{\texttt{precs}(\texttt{rt},\texttt{rip}) \mid (\texttt{rip},*) \in \texttt{dests}\}$⟧
⟦$\texttt{dests} := \{(\texttt{rip},\texttt{rsn}) \mid (\texttt{rip},\texttt{rsn}) \in \texttt{dests} \wedge \texttt{precs}(\texttt{rt},\texttt{rip}) \neq \emptyset\}$⟧
groupcast(pre,rerr(dests,ip)) . AODV(ip,sn,rt,rreqs,store)
$+$ [$\texttt{dip} \neq \texttt{ip}$] /* this node is not the destination node */
(
[$\texttt{dip} \in \texttt{vD}(\texttt{rt}) \wedge \texttt{dsn} \leq \texttt{sqn}(\texttt{rt},\texttt{dip}) \wedge \texttt{sqnf}(\texttt{rt},\texttt{dip}) = \texttt{kno}$] /* valid route to dip that is fresh enough */
/* update rt by adding precursors */
⟦$\texttt{rt} := \texttt{addpreRT}(\texttt{rt},\texttt{dip},\{\texttt{sip}\})$⟧
⟦$\texttt{rt} := \texttt{addpreRT}(\texttt{rt},\texttt{oip},\{\texttt{nhop}(\texttt{rt},\texttt{dip})\})$⟧
/* unicast a RREP towards the oip of the RREQ */
unicast(nhop(rt,oip),rrep(dhops(rt,dip),dip,sqn(rt,dip),oip,ip)) .

Case Study: AODV

- full specification of AODV (IETF Standard)
- specification details
  - around 5 types and 30 functions
  - around 120 lines of specification
    (in contrast of 40 pages English prose)
- performed rigorous analysis
  (out of scope for today)

Summary

- description language for (wireless networks)
- key features:
  - guarantee broadcast
  - conditional unicast
  - data handling
- case study
  - full concise specification of AODV (RFC 3561) (no time)
- basis for formal analysis

[1] *A Process Algebra for Wireless Mesh Networks.*
A. Fehnker, R. J. van Glabbeek, P. Höfner, A. McIver, M. Portmann, W. L. Tan.
In European Symposium on Programming, LNCS 7211, 295-315 Springer, 2012.

[2] *A Rigorous Analysis of AODV and Its Variants*.
P. Höfner, W. L. Tan, R. J. van Glabbeek, M. Portmann, A. McIver, A. Fehnker.
In Modeling, Analysis and Simulation of Wireless and Mobile Systems, 2012.

[3] *A Process Algebra for Wireless Mesh Networks used for Modelling, Verifying and Analysing AODV*.
A. Fehnker, R. J. van Glabbeek, P. Höfner, A. McIver, M. Portmann, W. L. Tan.
Technical report 5513, NICTA, 2013.

Coming Soon?

NICTA

- Manual Verification using Invariant Proofs
- Model Checking of Network Protocols
- Quantitative Analysis of Network Protocols using Statistical Model Checking
- (Mechanised Verification of Network Protocols)