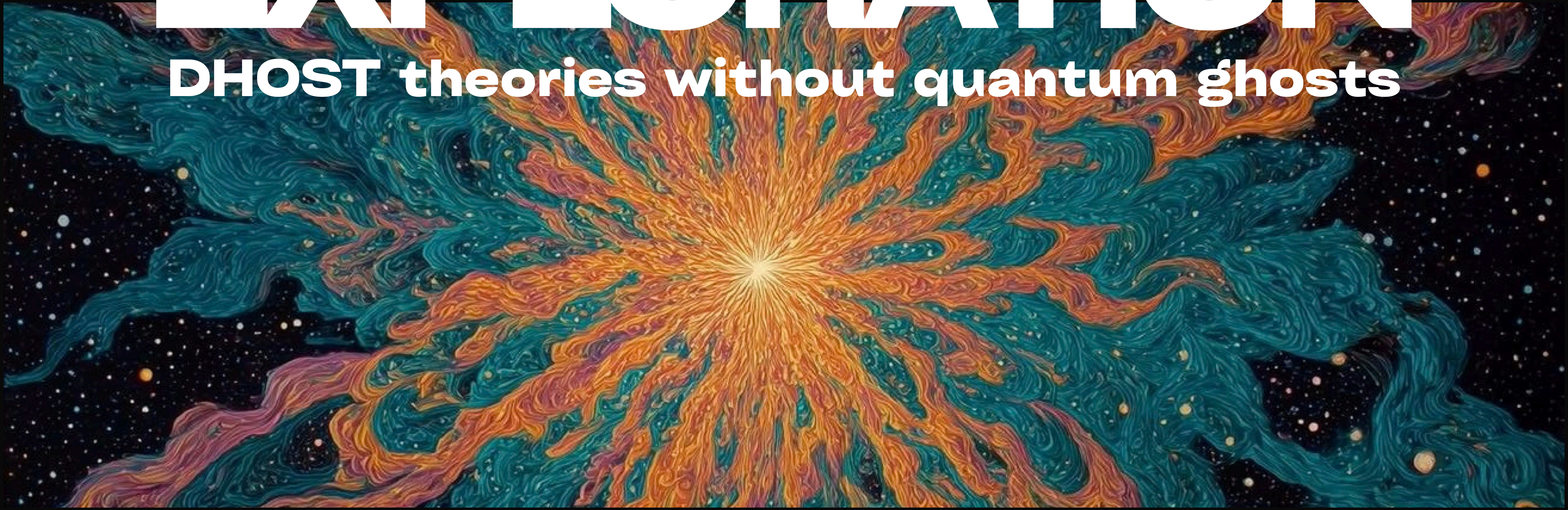
Ginevra Braga
ginevra.braga@gssi.it

AI-ASSISTED EXPLORATION

DHOST theories without quantum ghosts



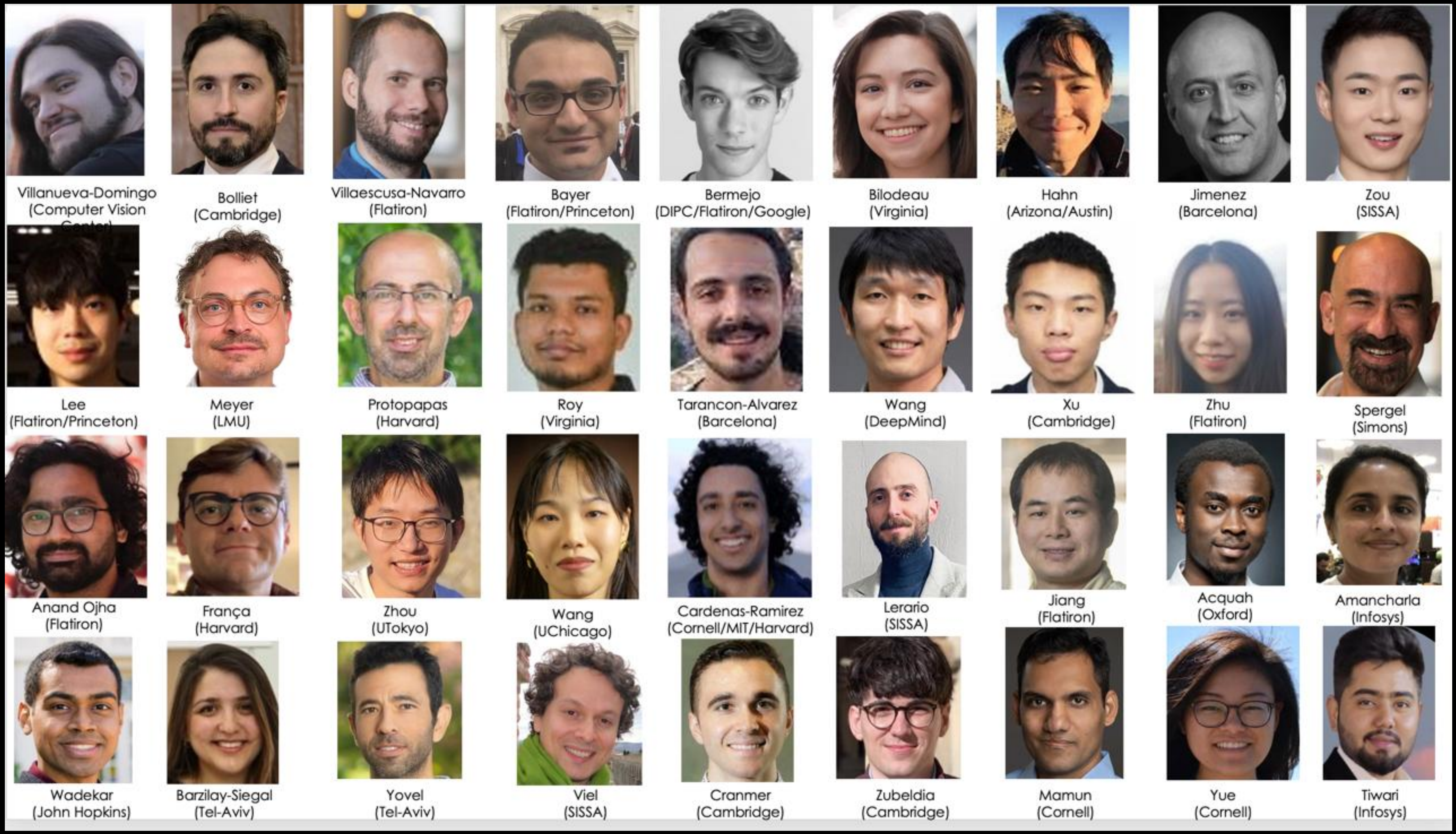
GeomGravX

OUTLINE

- What is DENARIO?
- For which physical problem did we use it?
- How does it work?
- Preliminary results

DENARIO

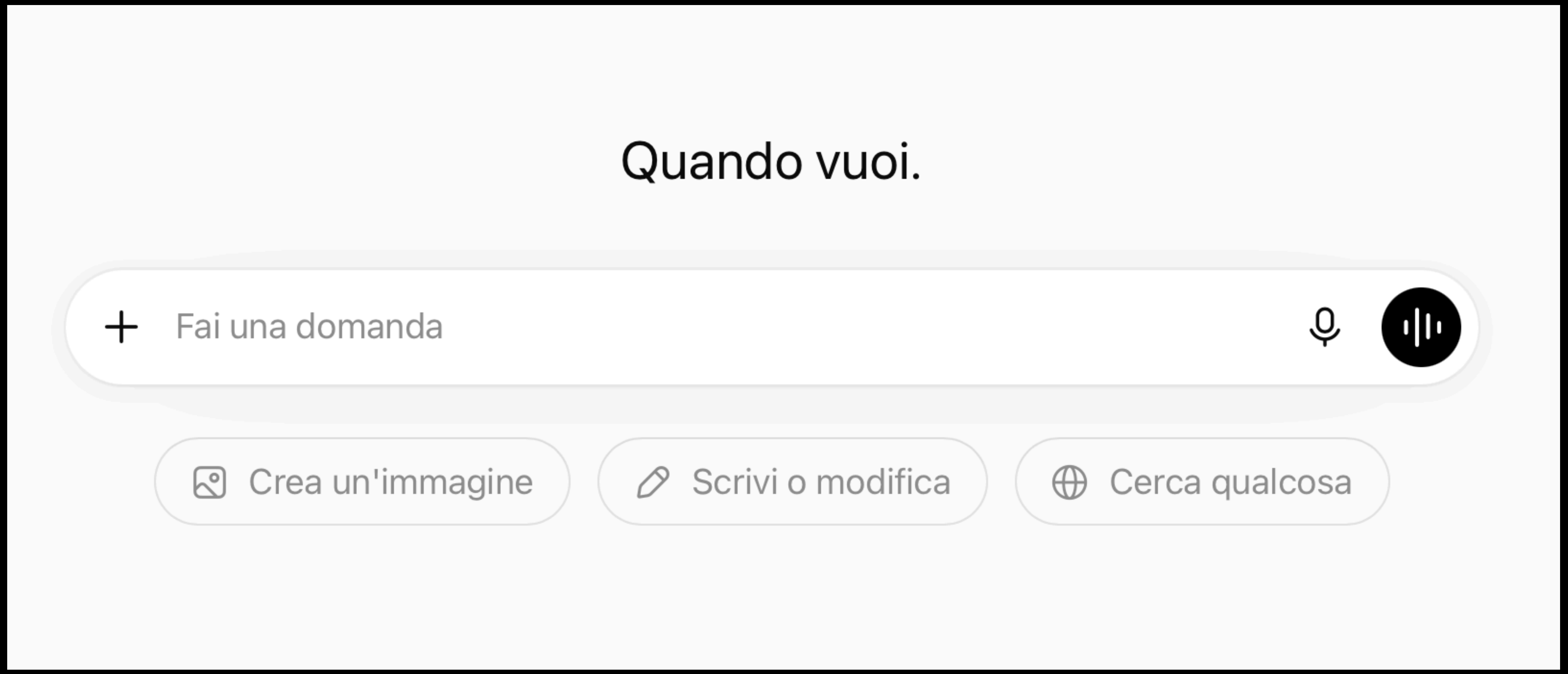
The DENARIO project: DEep kNowledge Agents foR scIentific discOvery

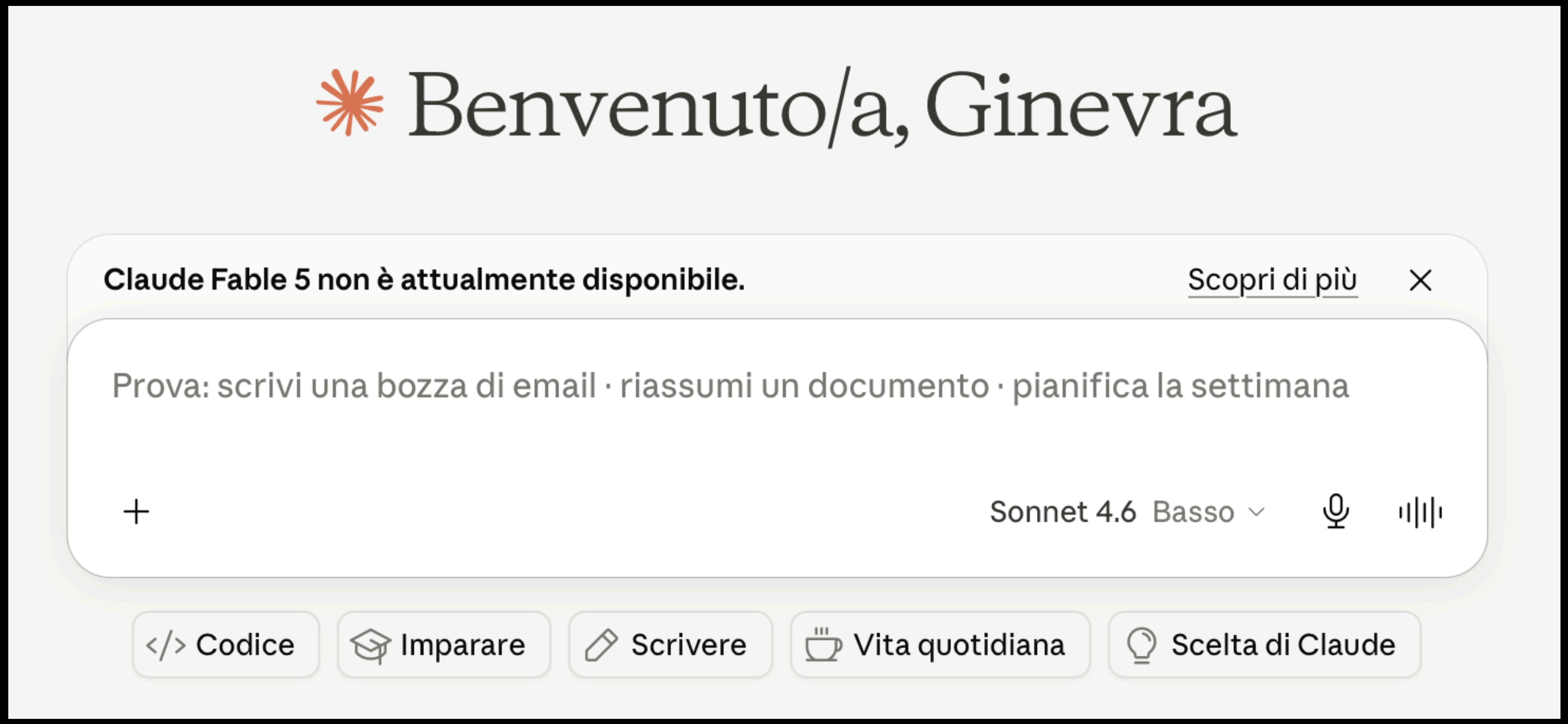


Physics
Mathemathics
Biology
Philosophy
Ingenieeering
...

DENARIO

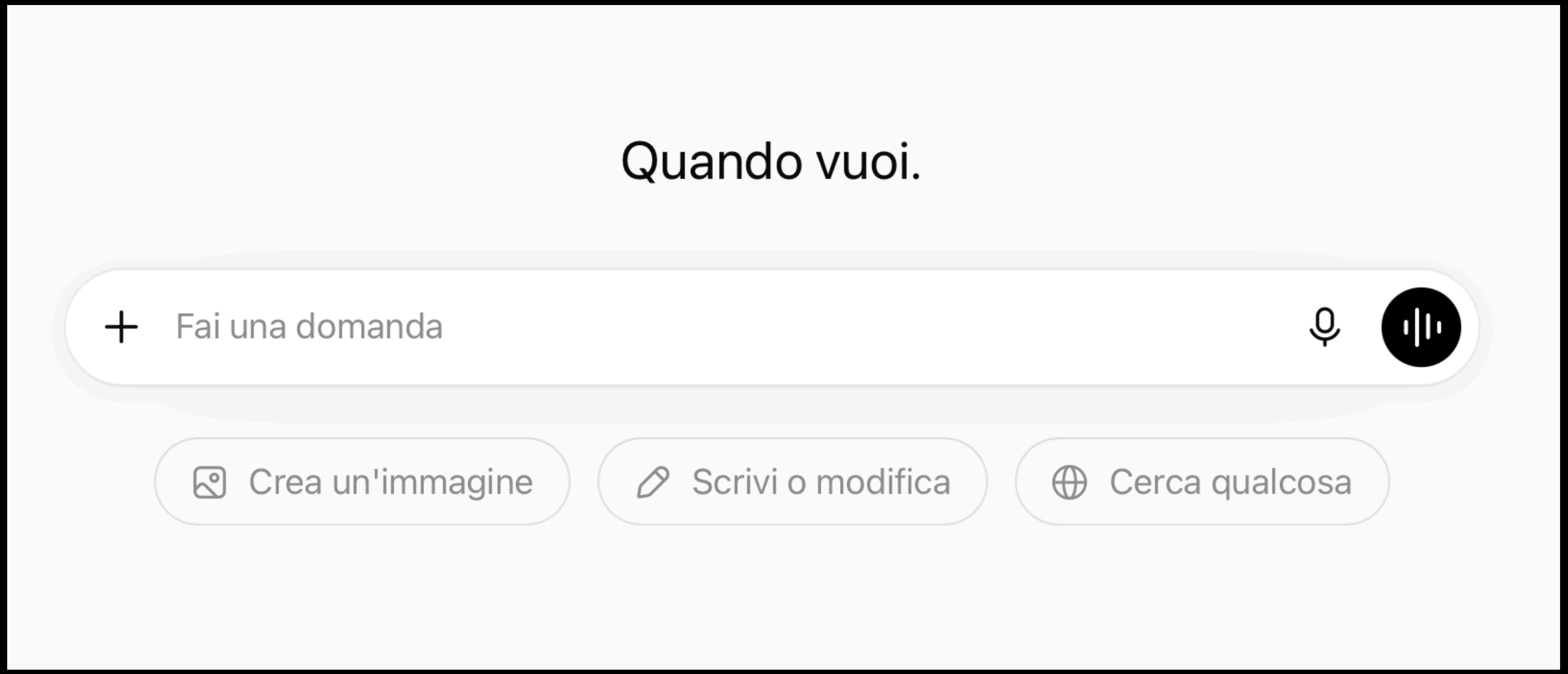
AI Agent: LLM with decision making capability

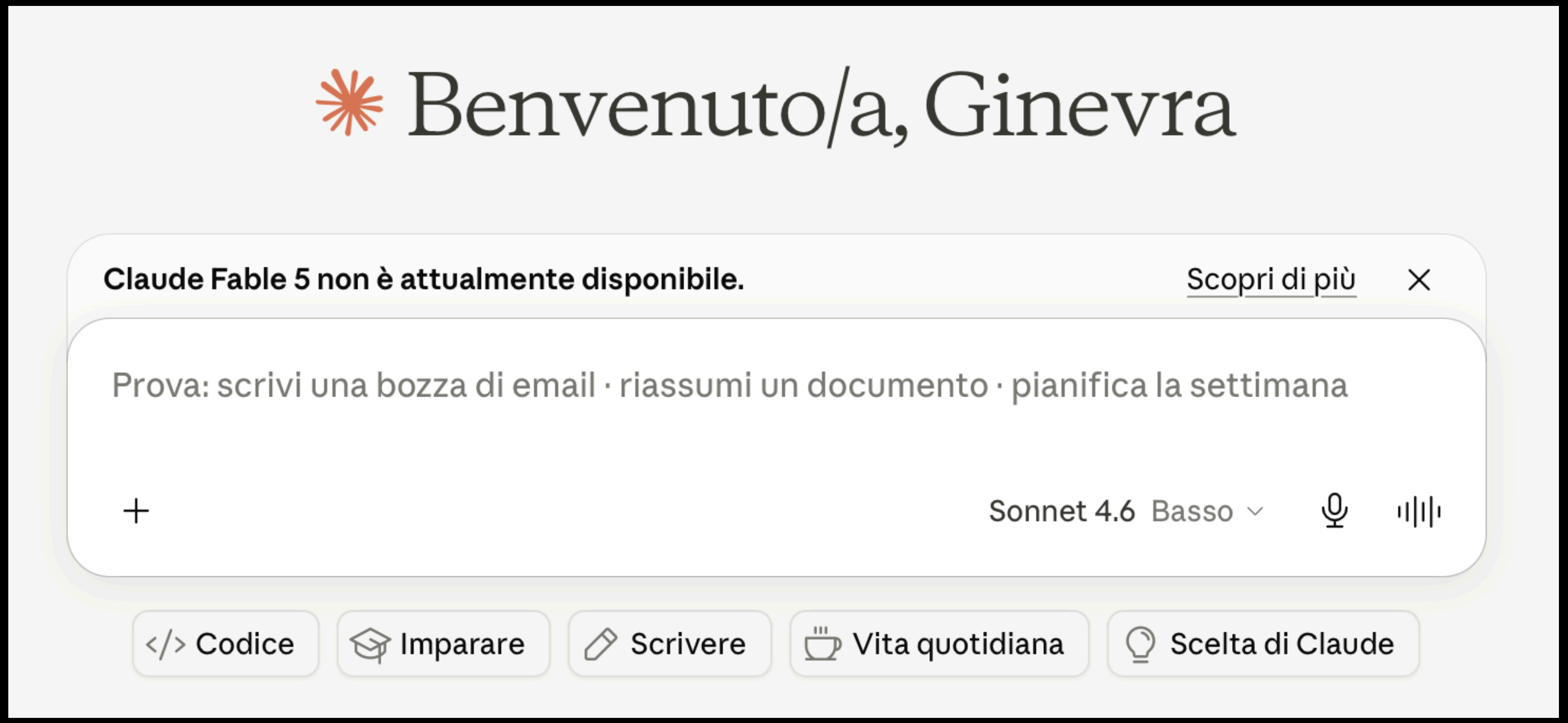




DENARIO

AI Agent: LLM with decision making capability

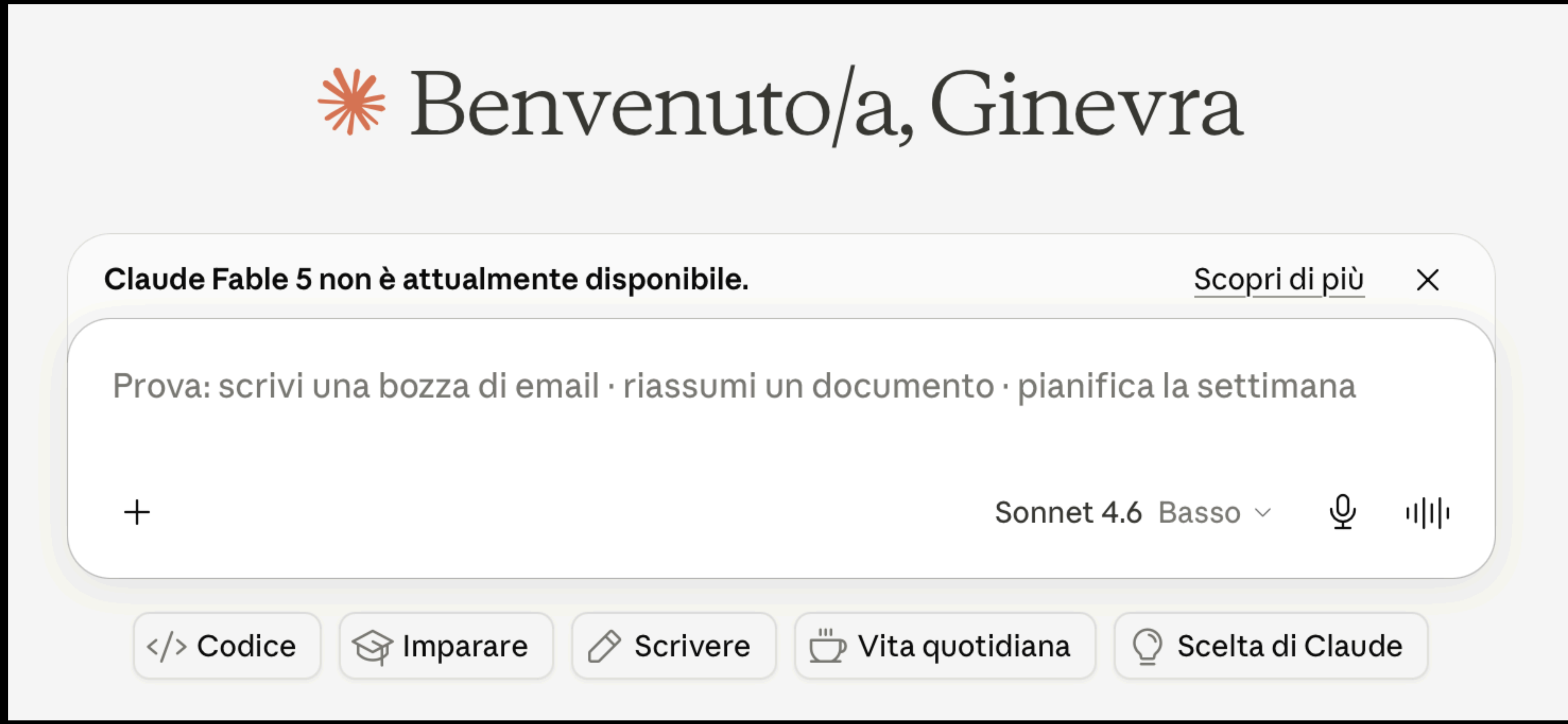




AI Multi-Agent: Autonomous system composed by many number of agents

DENARIO

AI Agent: LLM with decision making capability

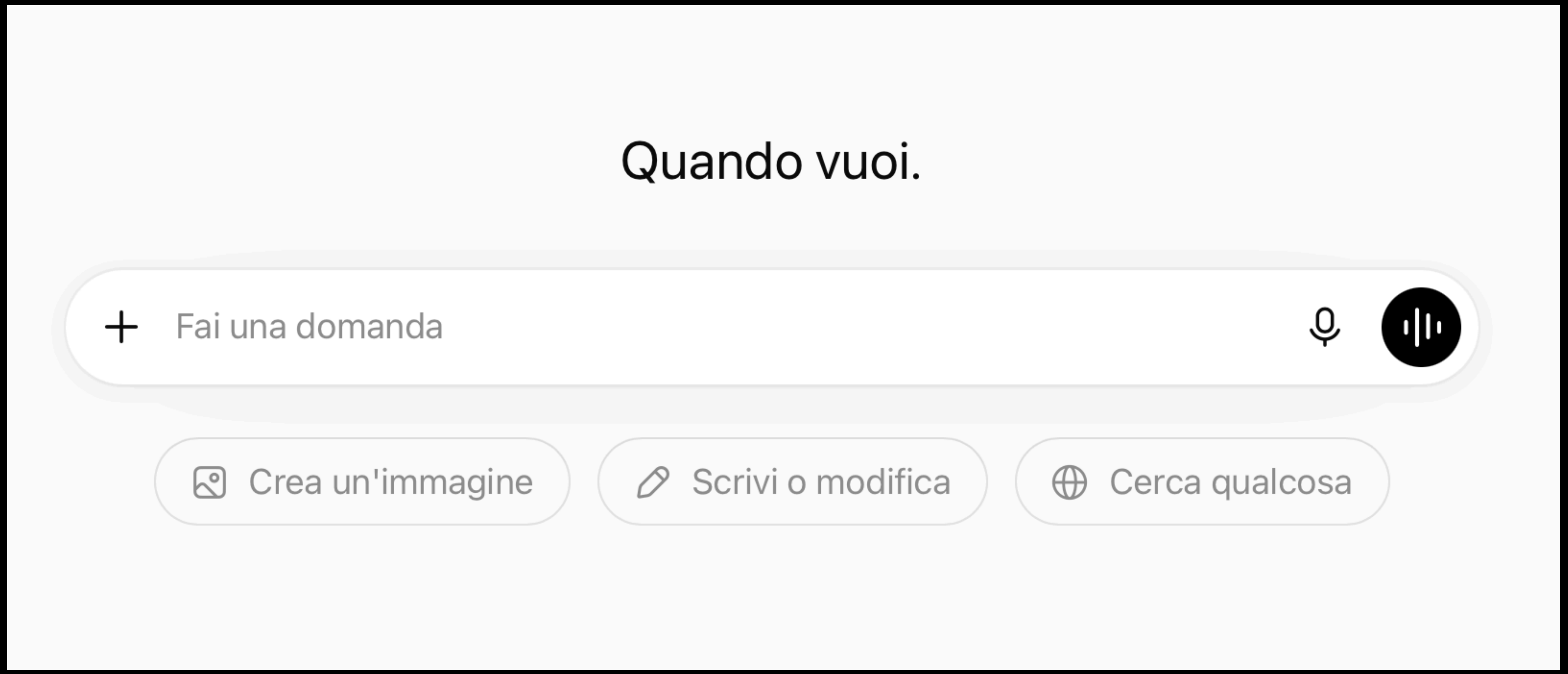


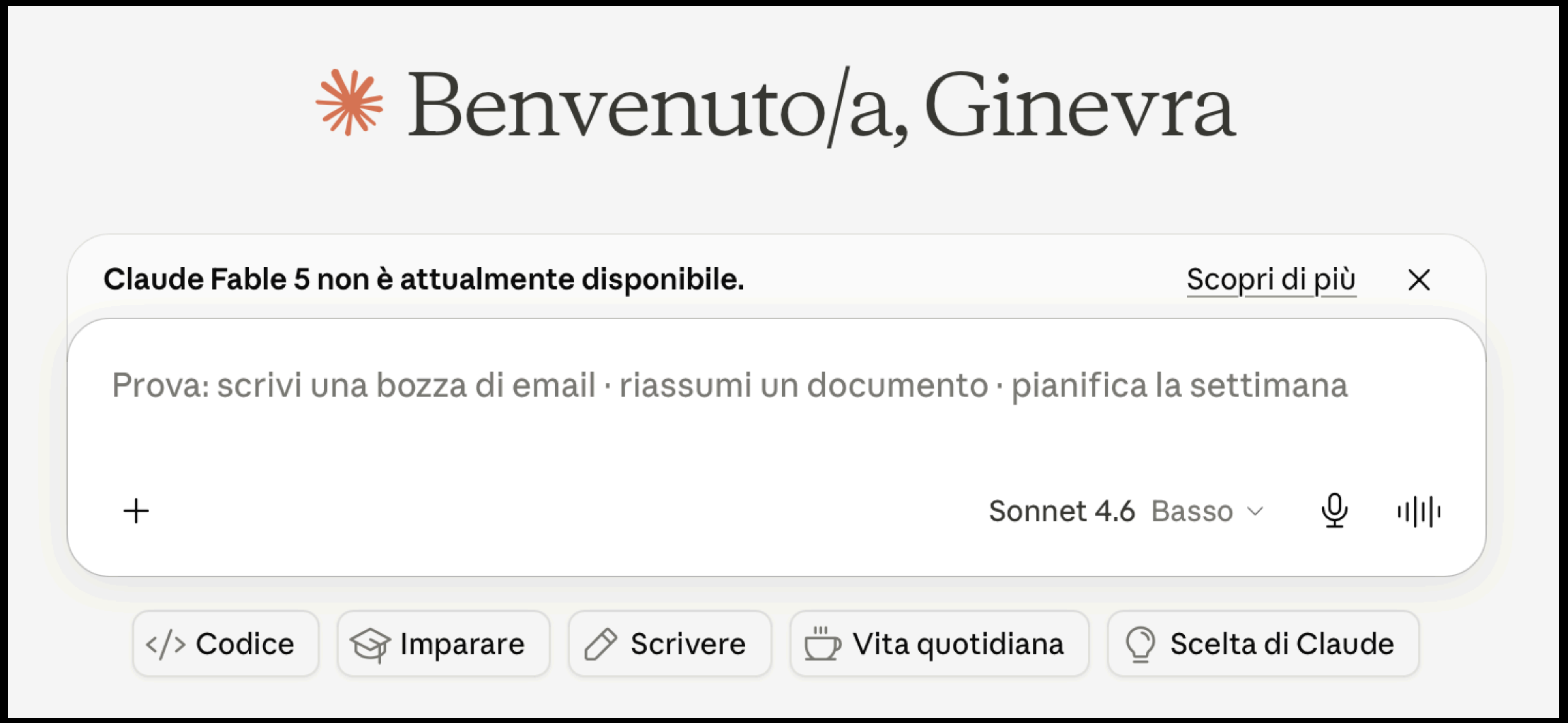
AI Multi-Agent: Autonomous system composed by many number of agents

- Agents can be specialized for different tasks

DENARIO

AI Agent: LLM with decision making capability





AI Multi-Agent: Autonomous system composed by many number of agents

- Agents can be specialized for different tasks
- Different relations among agents

DENARIO

- AI multi-agent system designed to be a scientific research assistant

DENARIO

- AI multi-agent system designed to be a scientific research assistant
- Generate ideas, check the literature, develop research plans, write and execute code, make plots, and write a scientific paper

DENARIO

- AI multi-agent system designed to be a scientific research assistant
- Generate ideas, check the literature, develop research plans, write and execute code, make plots, and write a scientific paper
- Modular system: multi agent orchestration with AG2 and LangGraph

https://ag2.ai/

DENARIO

- AI multi-agent system designed to be a scientific research assistant
- Generate ideas, check the literature, develop research plans, write and execute code, make plots, and write a scientific paper
- Modular system: multi agent orchestration with AG2 and LangGraph

https://ag2.ai/

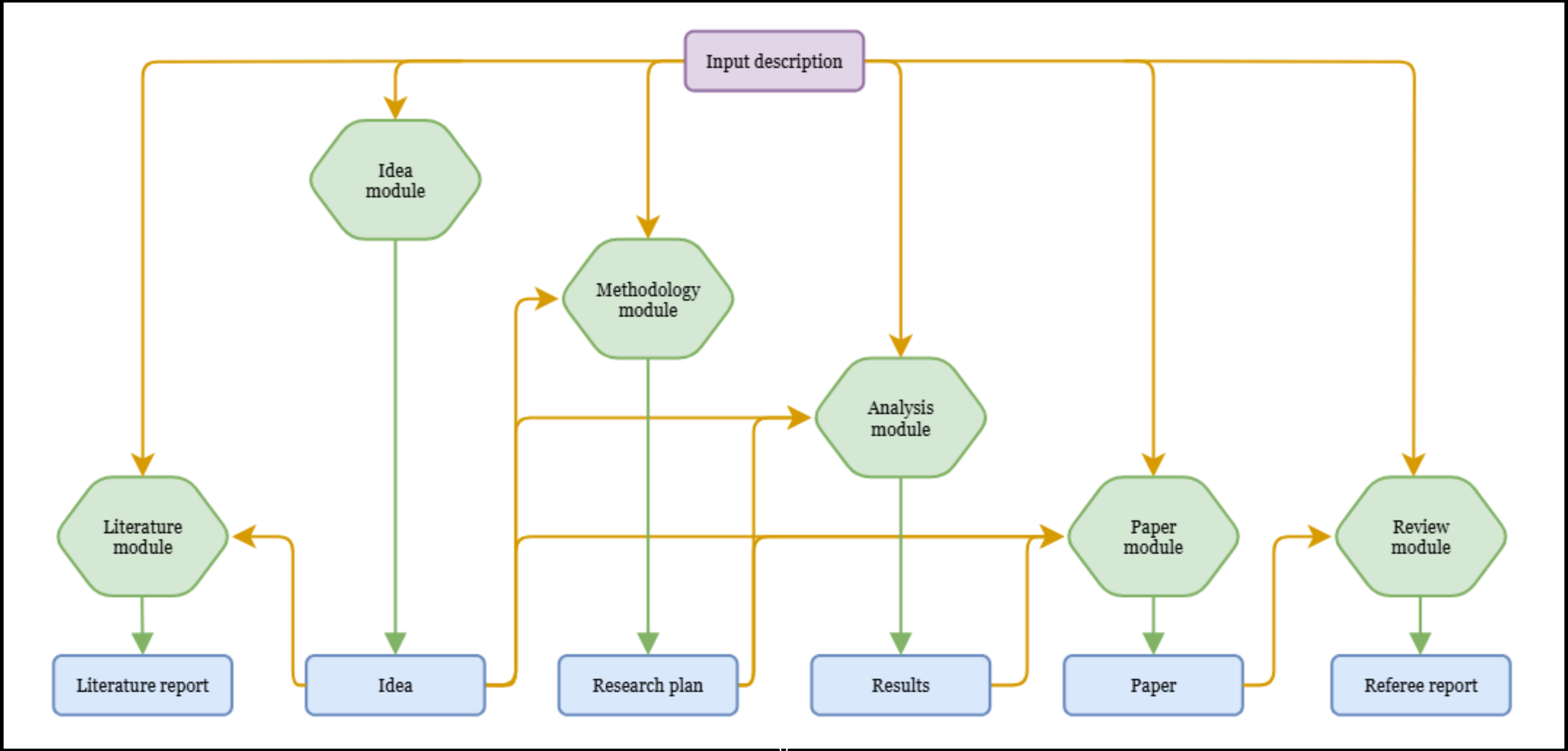
- Plan and Control is done with cmbagent

https://github.com/CMBAgents/cmbagent

DENARIO: The Architecture

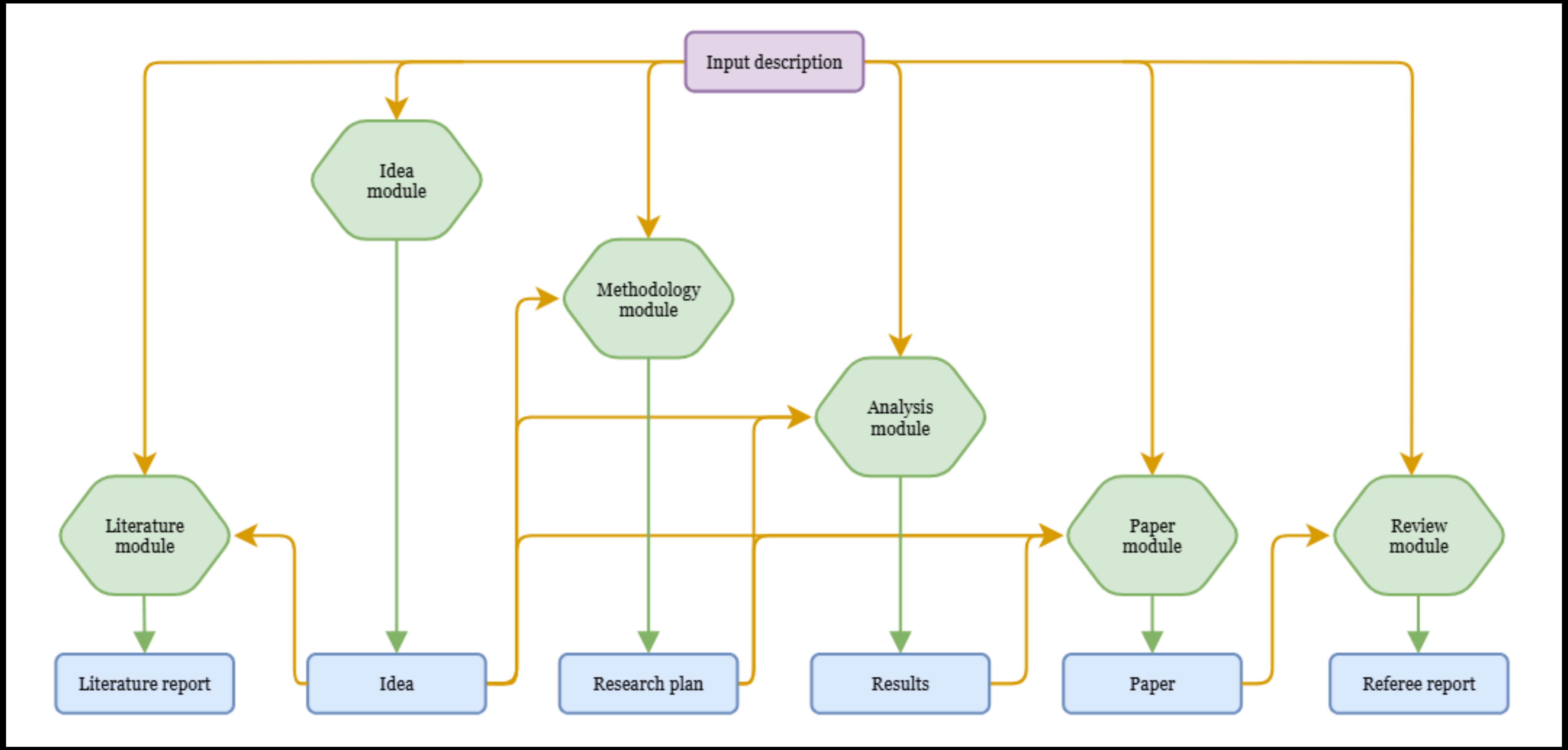
https://github.com/AstroPilot-AI/Denario

Version 2.0 out in a couple of months



DENARIO: The Architecture

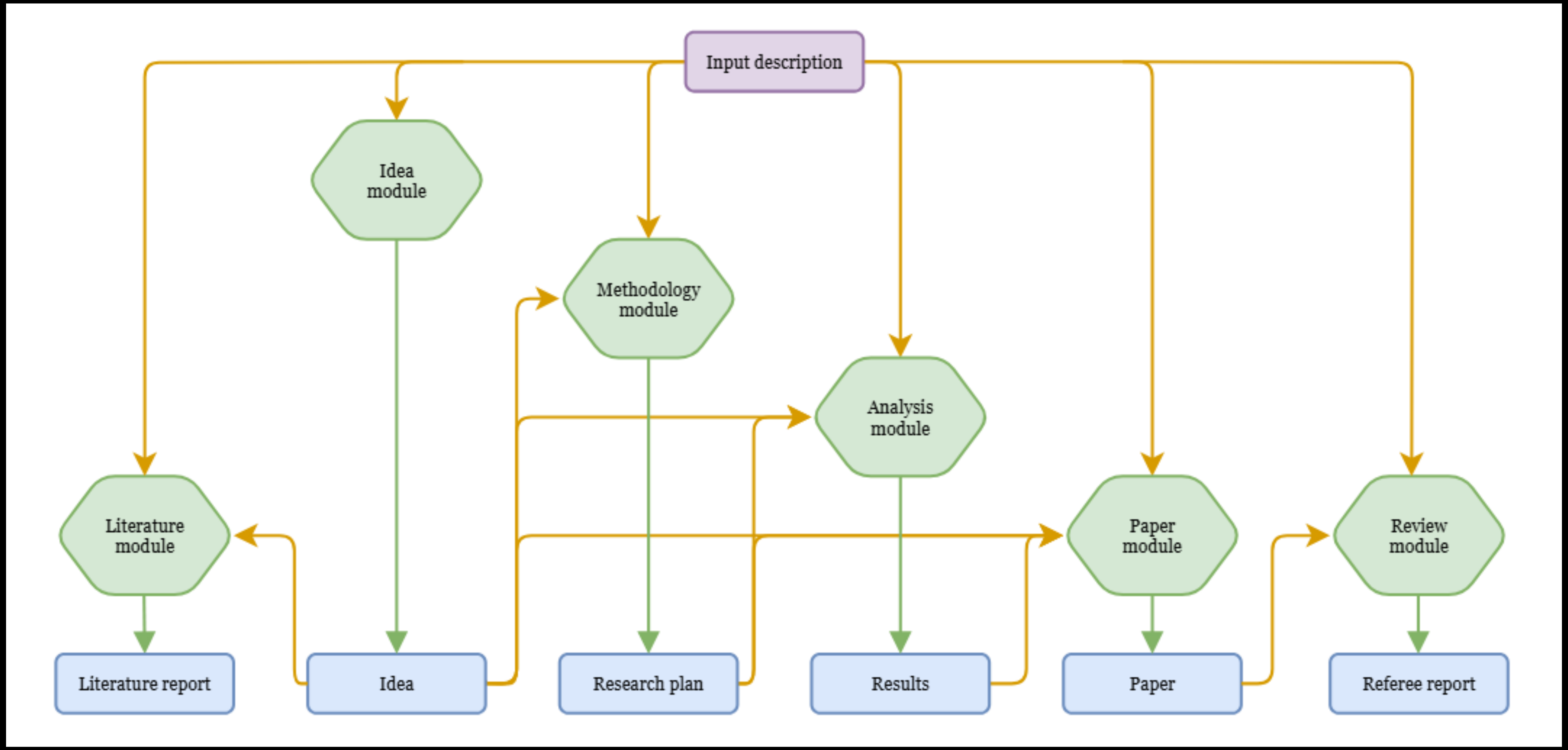
- **Input description:** will initially guide the system towards the final result



DENARIO: The Architecture

- **Input description:** will initially guide the system towards the final result

- It can contain data, topic to investigate, analysis that we want to perform, key points…

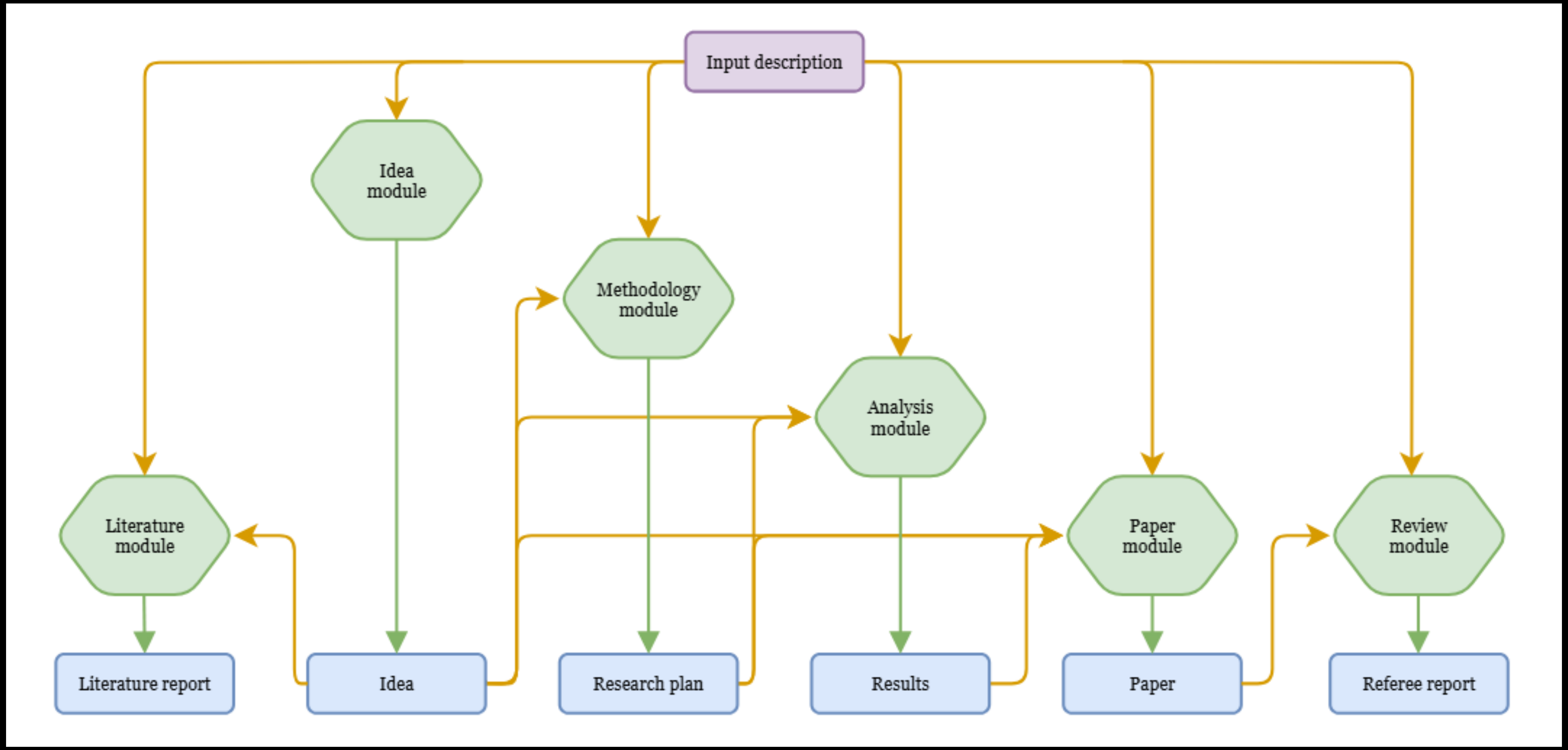


DENARIO: The Architecture

- **Input description:** will initially guide the system towards the final result

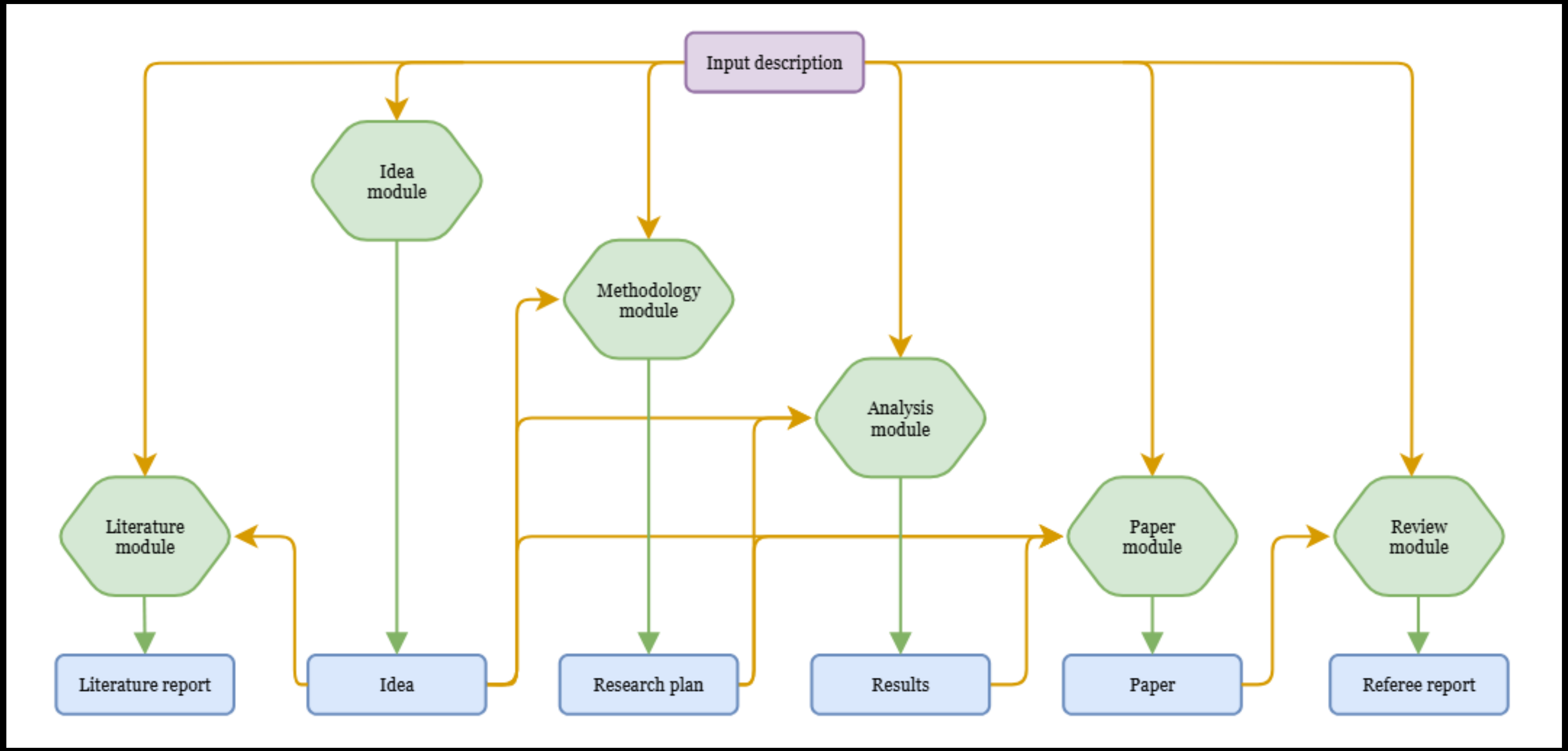
- It can contain data, topic to investigate, analysis that we want to perform, key points…

- The **input.md** file will be given to the consecutive modules



DENARIO: The Architecture

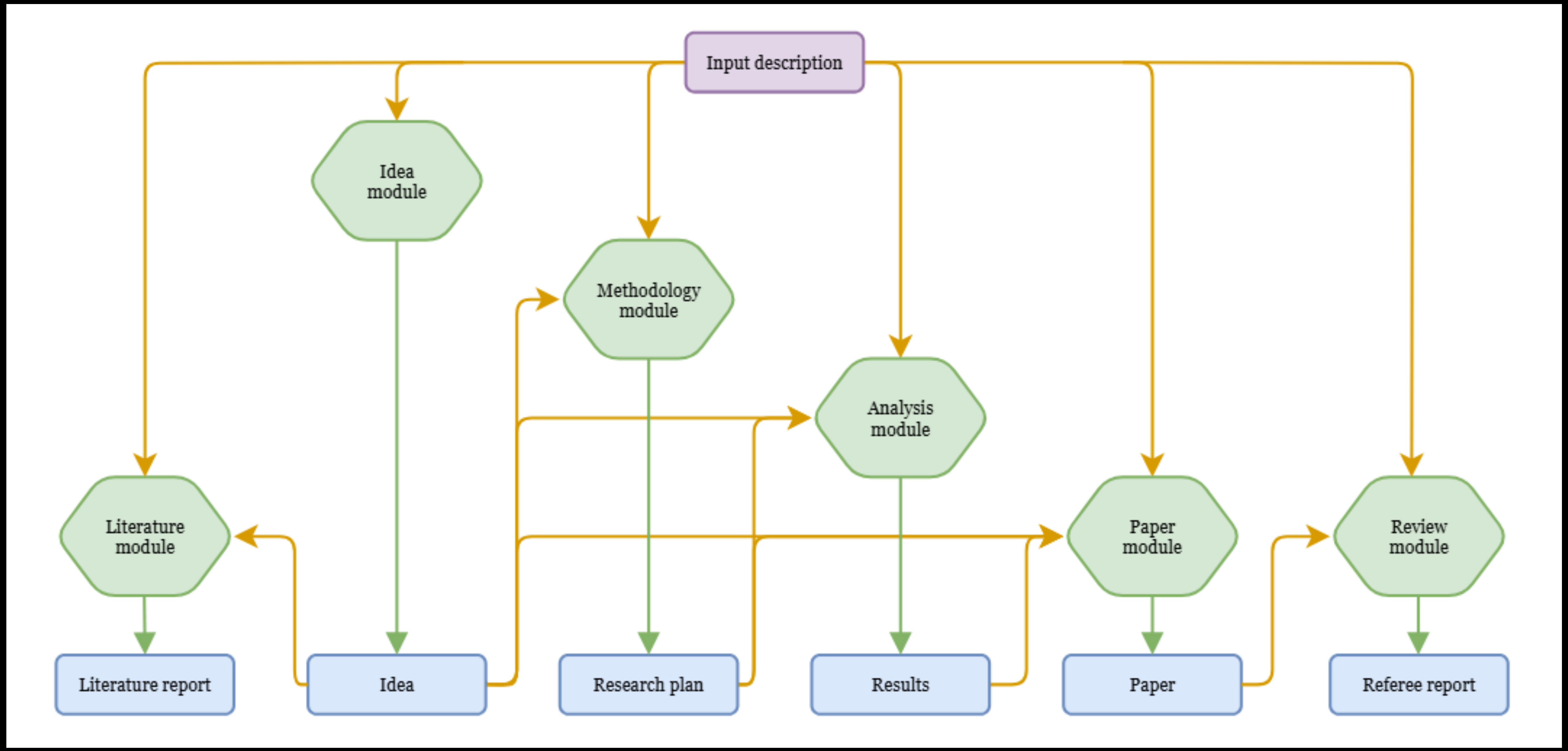
- **Idea module:** Takes **input.md** and produce a file **idea.md**



DENARIO: The Architecture

- **Idea module:** Takes **input.md** and produce a file **idea.md**

- Goal: generate a (hopefully) innovative idea given the initial data

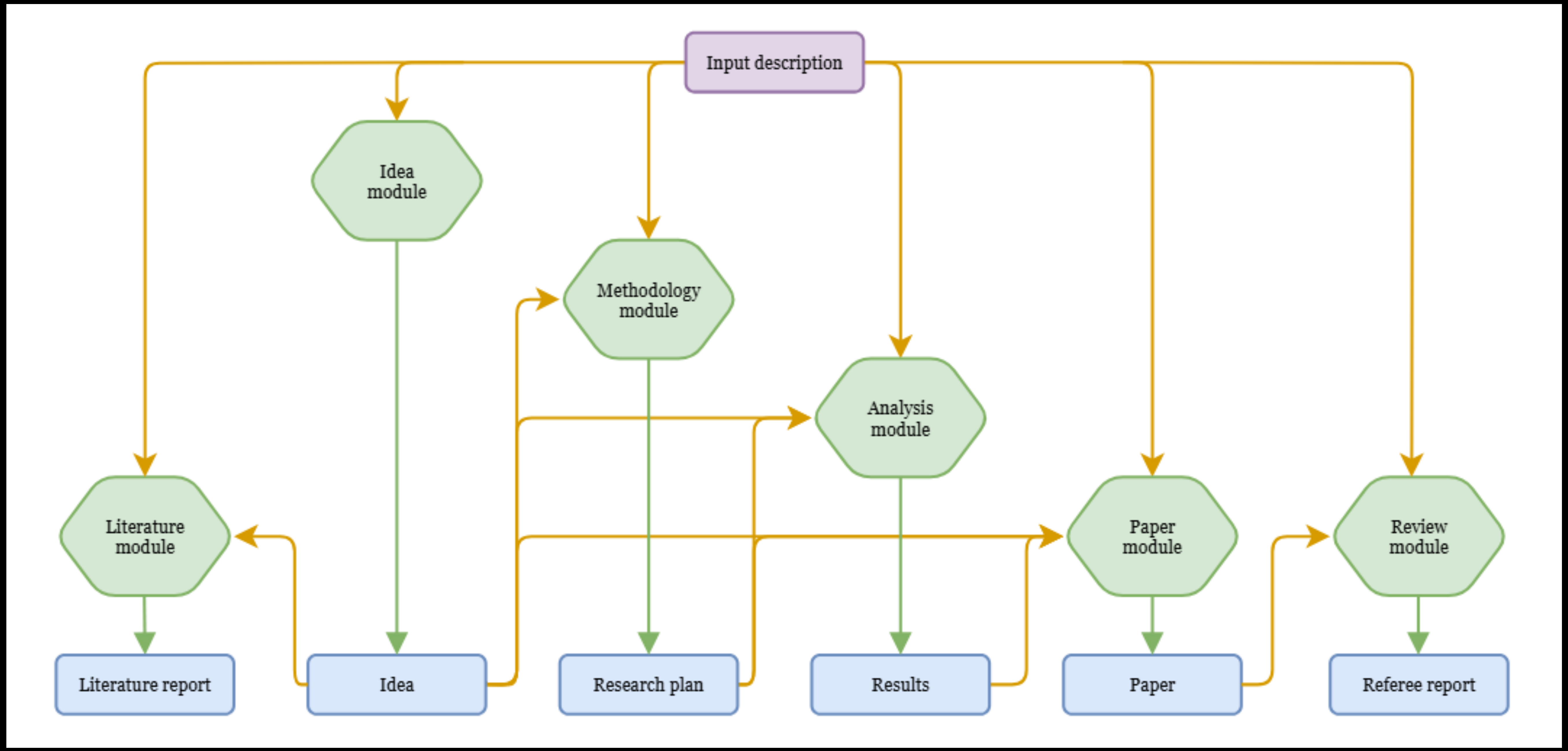


DENARIO: The Architecture

- **Idea module:** Takes **input.md** and produce a file **idea.md**

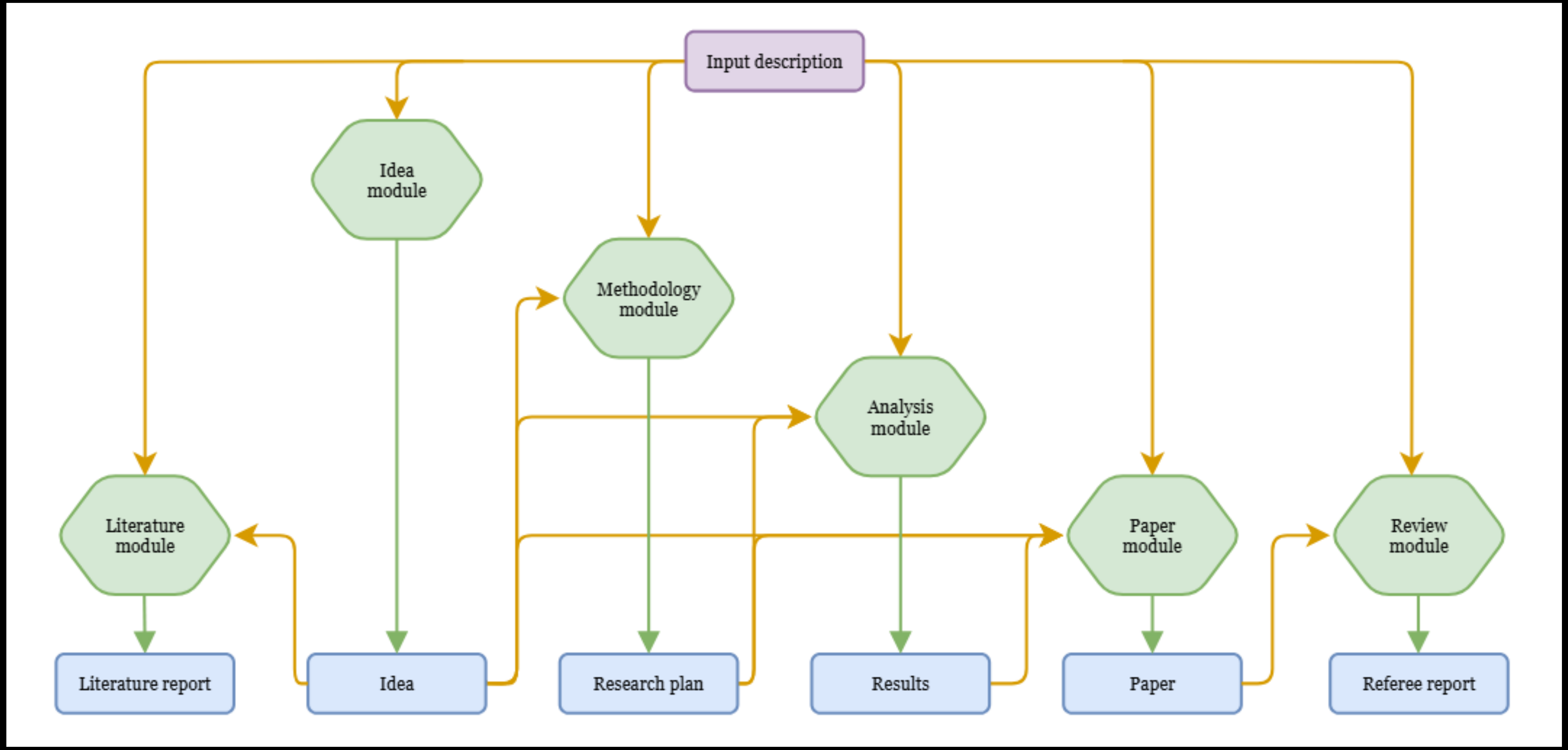
- Goal: generate a (hopefully) innovative idea given the initial data

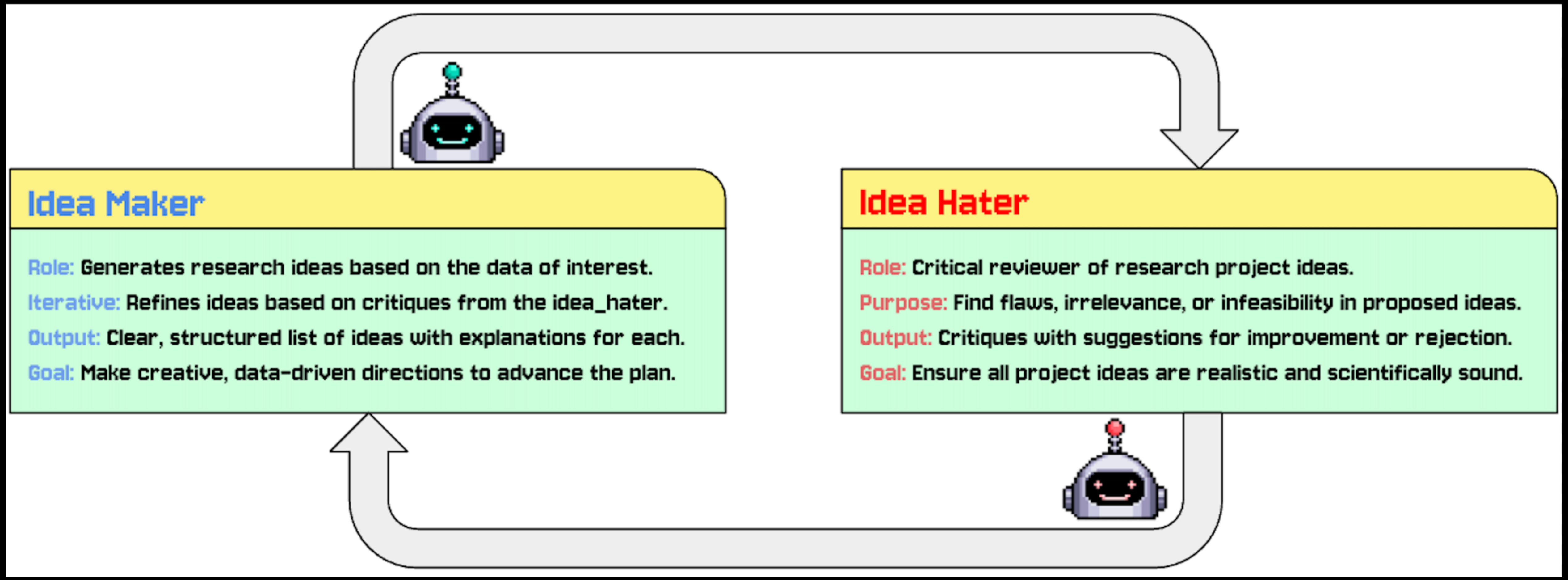
- The pipeline tries to mirror the natural human process of idea development



DENARIO: The Architecture

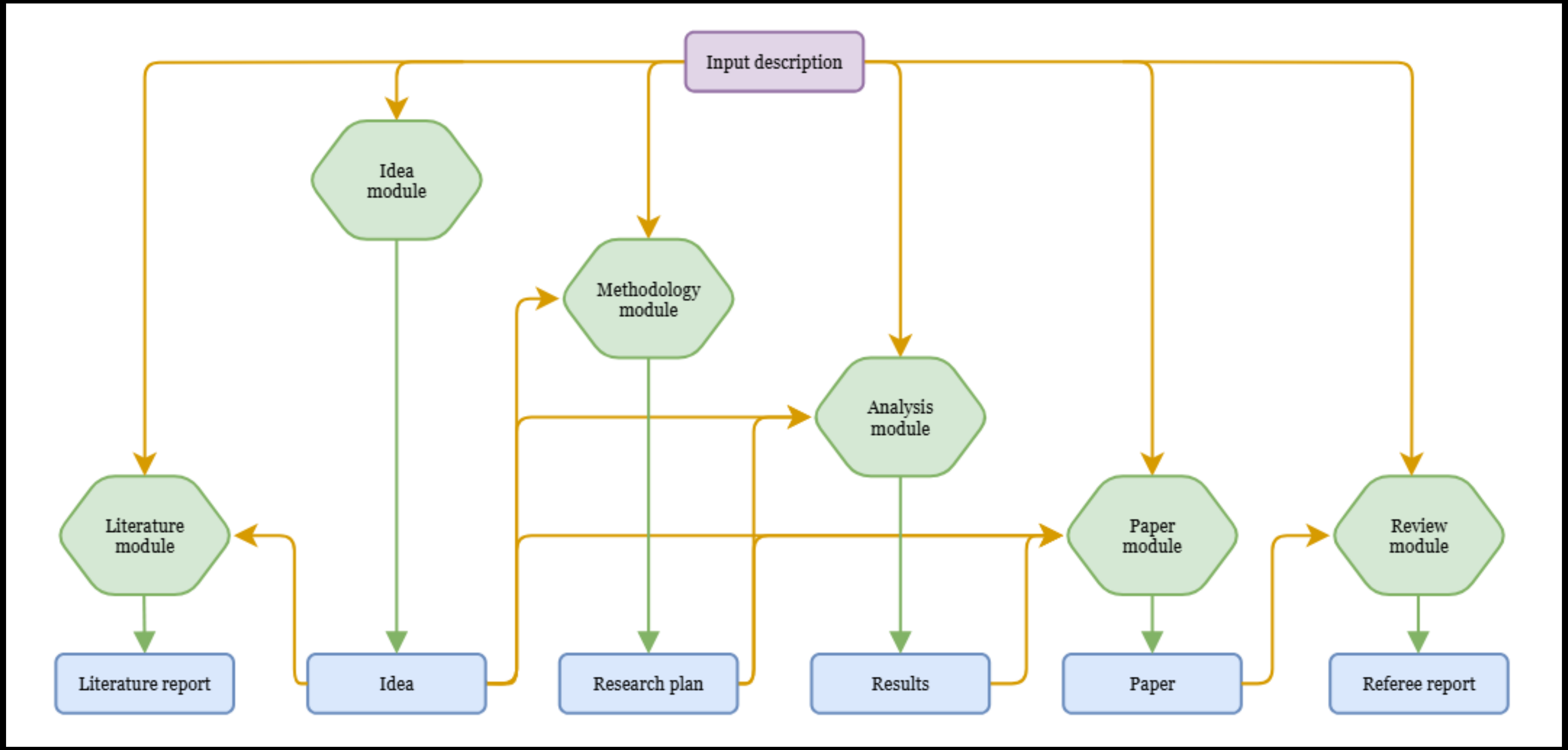
- **Idea module:** Takes **input.md** and produce a file **idea.md**
- Goal: generate a (hopefully) innovative idea given the initial data
- The pipeline tries to mirror the natural human process of idea development





DENARIO: The Architecture

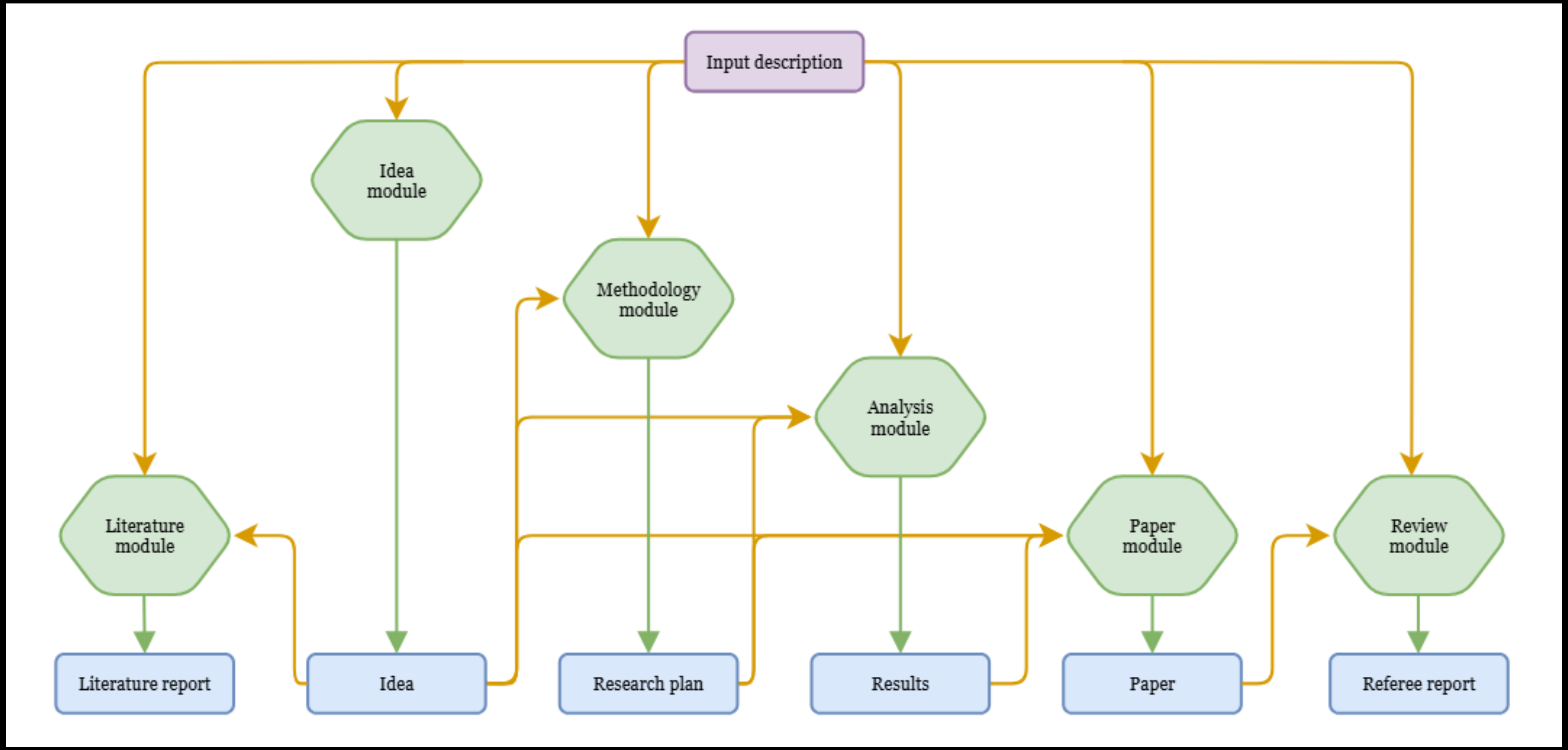
- **Literature module:** Takes input.md and idea.md and will produce a literature review



DENARIO: The Architecture

- **Literature module:** Takes **input.md** and **idea.md** and will produce a literature review

- Goal: determine whether the idea is original or not

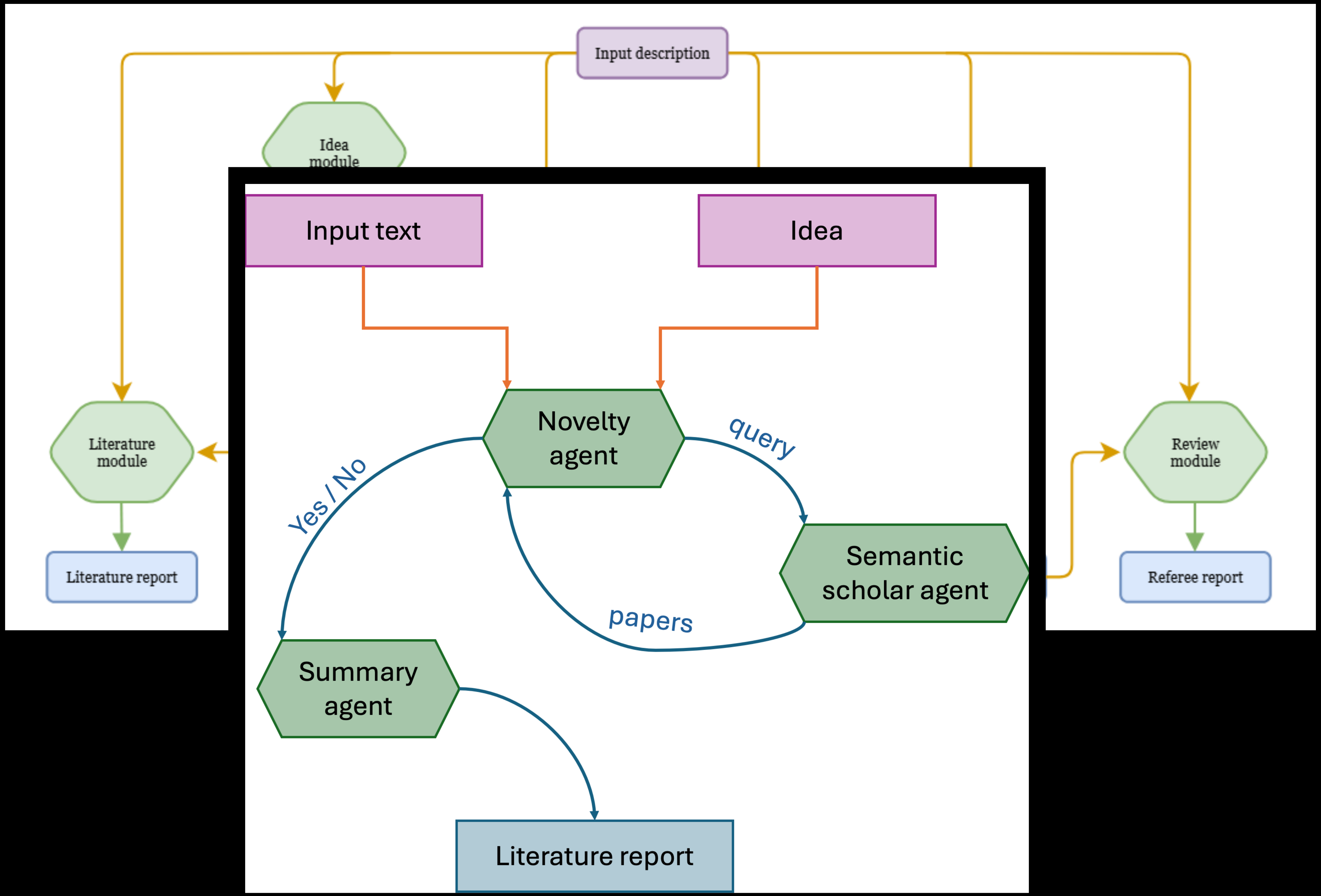


DENARIO: The Architecture

- **Literature module:** Takes **input.md** and **idea.md** and will produce a literature review

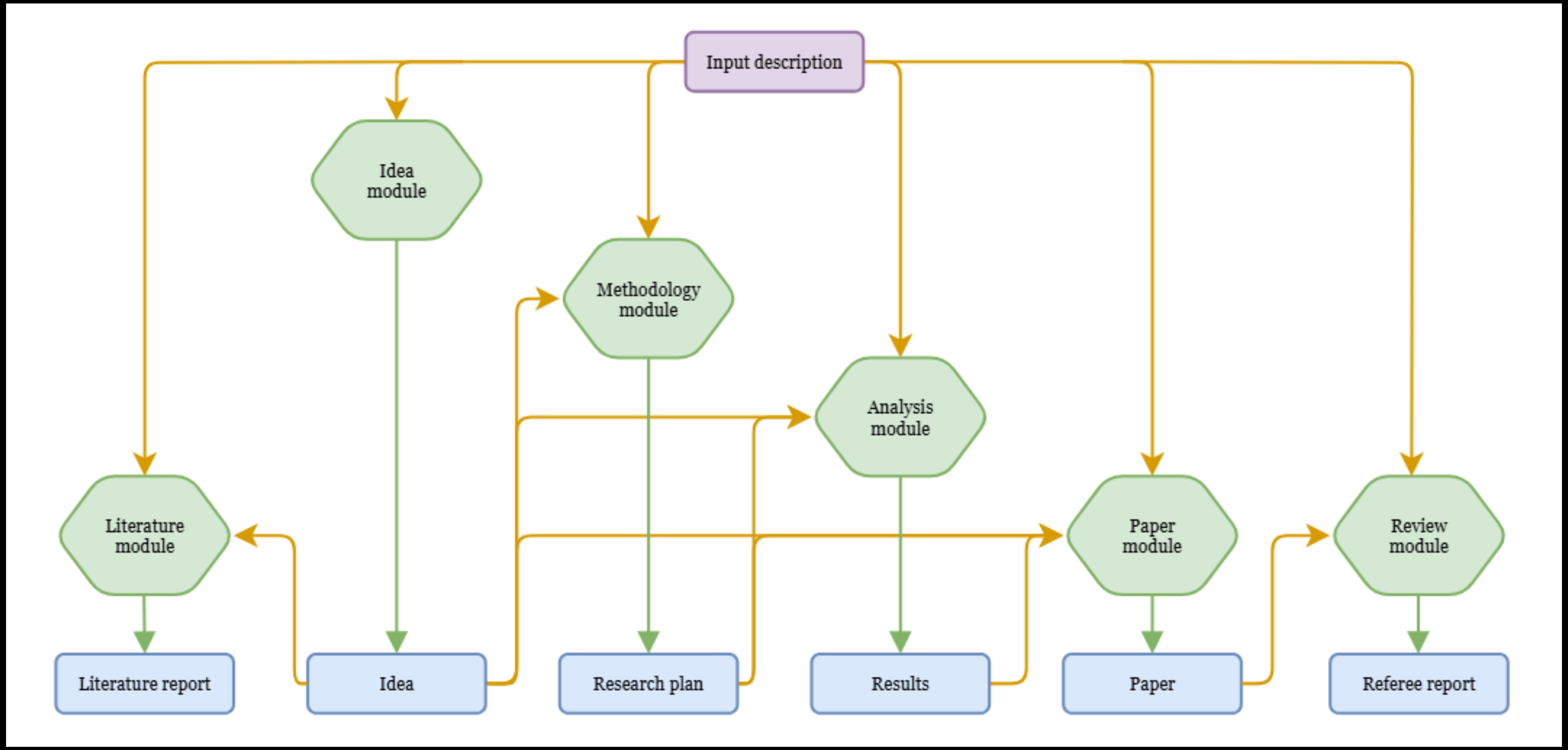
- Goal: determine whether the idea is original or not

- Composed by three agents



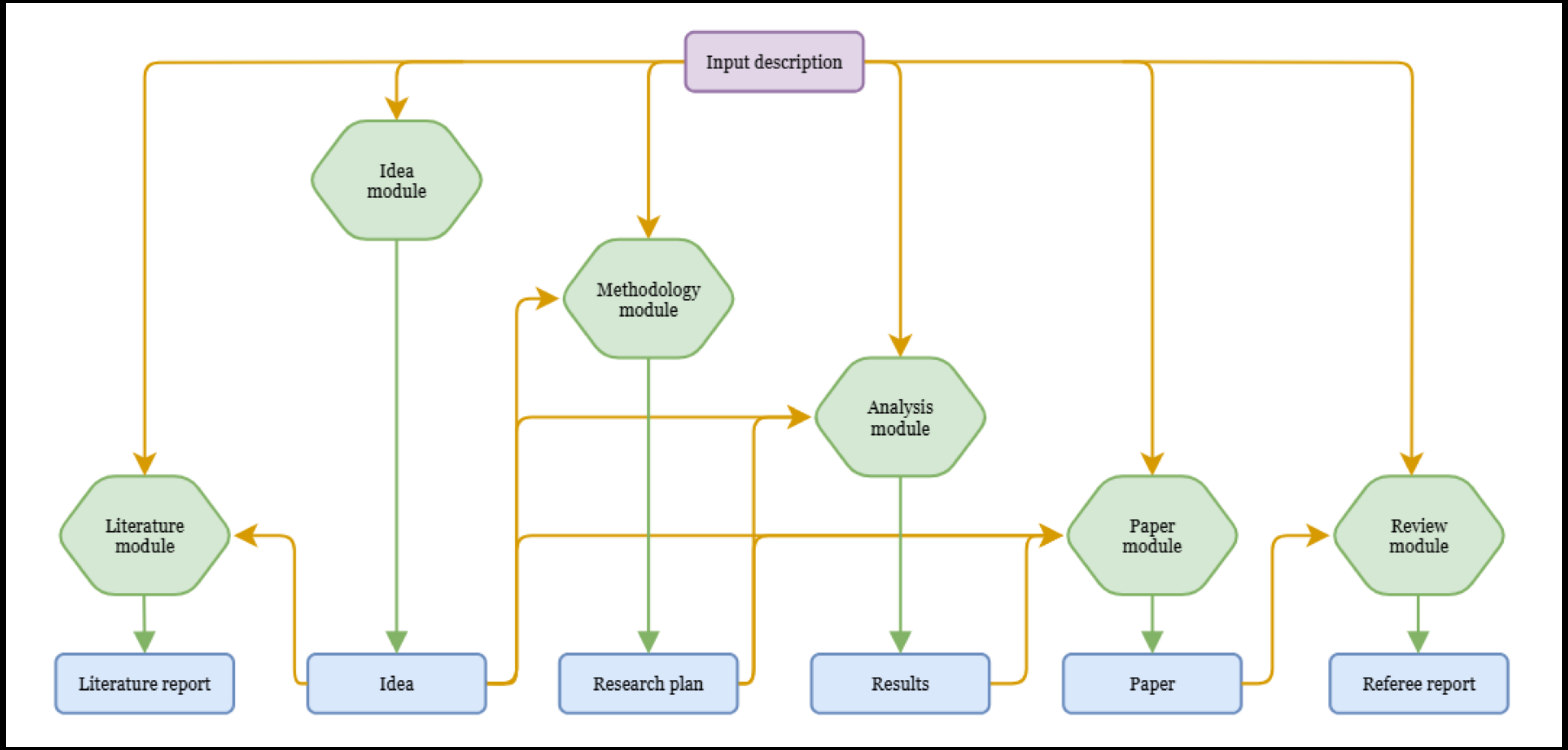
DENARIO: The Architecture

- **Methodology module:** Takes **input.md** and **idea.md** and will produce **methods.md**



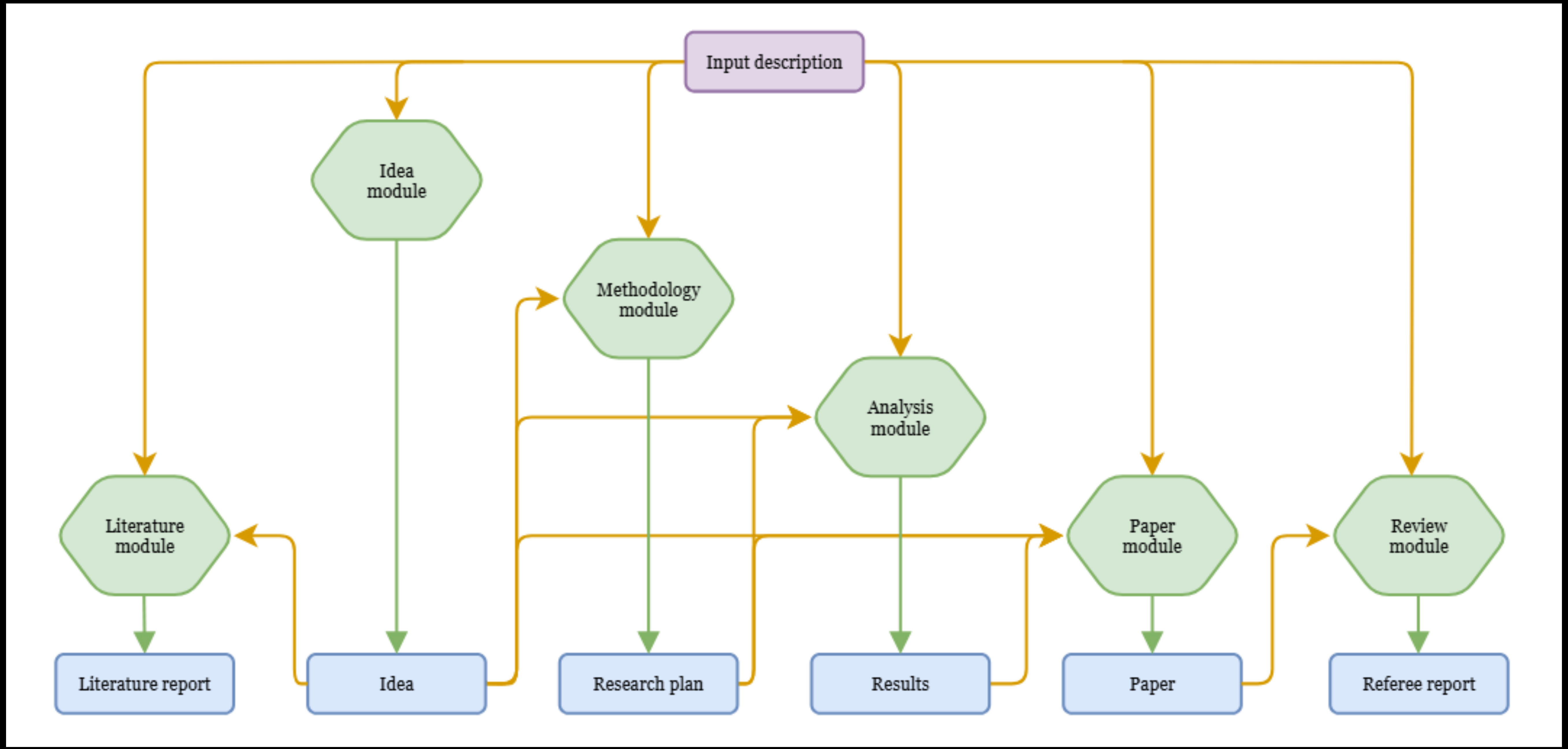
DENARIO: The Architecture

- **Methodology module:** Takes **input.md** and **idea.md** and will produce **methods.md**
- Goal: produce plan and methodology to tackle the problem



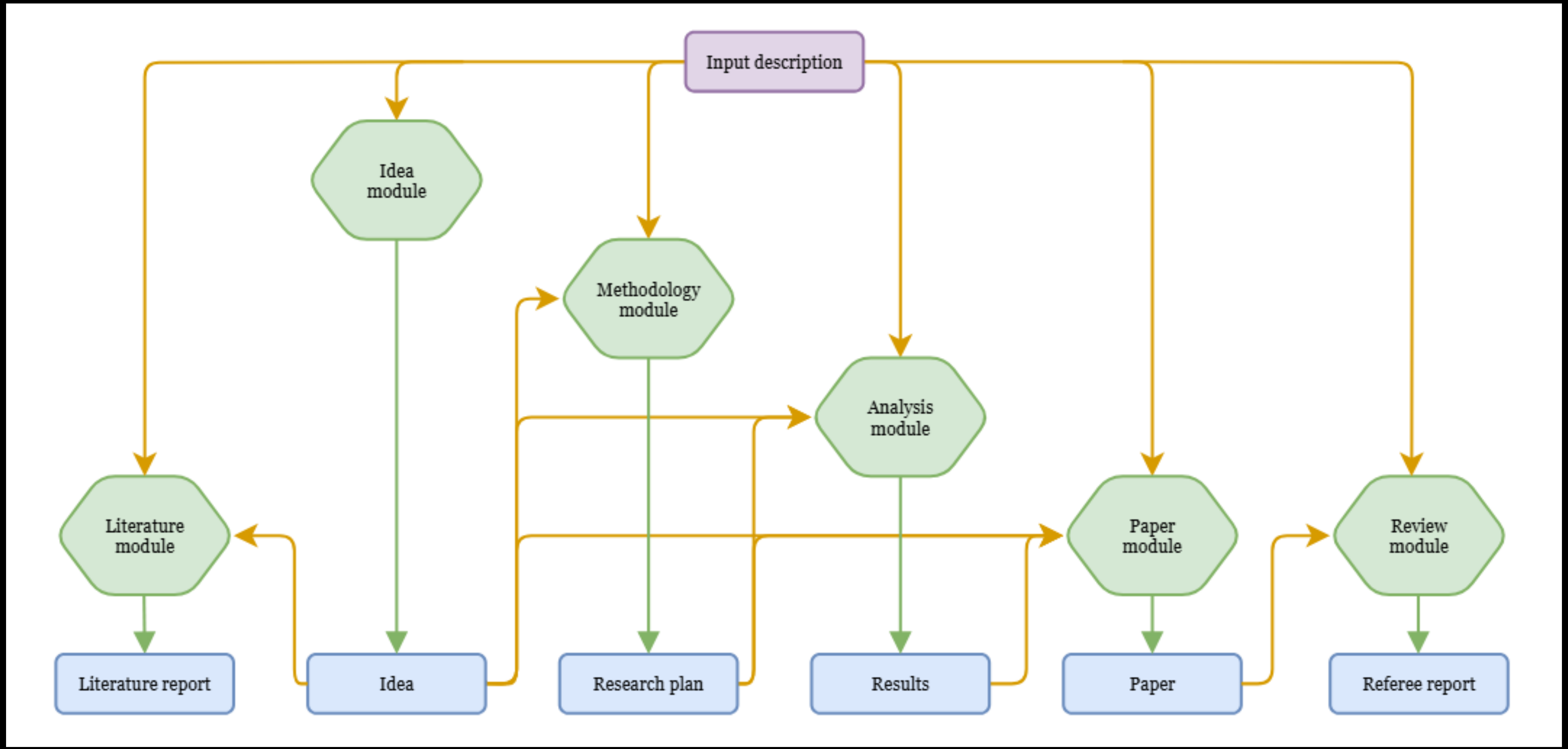
DENARIO: The Architecture

- **Methodology module:** Takes **input.md** and **idea.md** and will produce **methods.md**
- Goal: produce plan and methodology to tackle the problem
- The output will be a detailed research plan



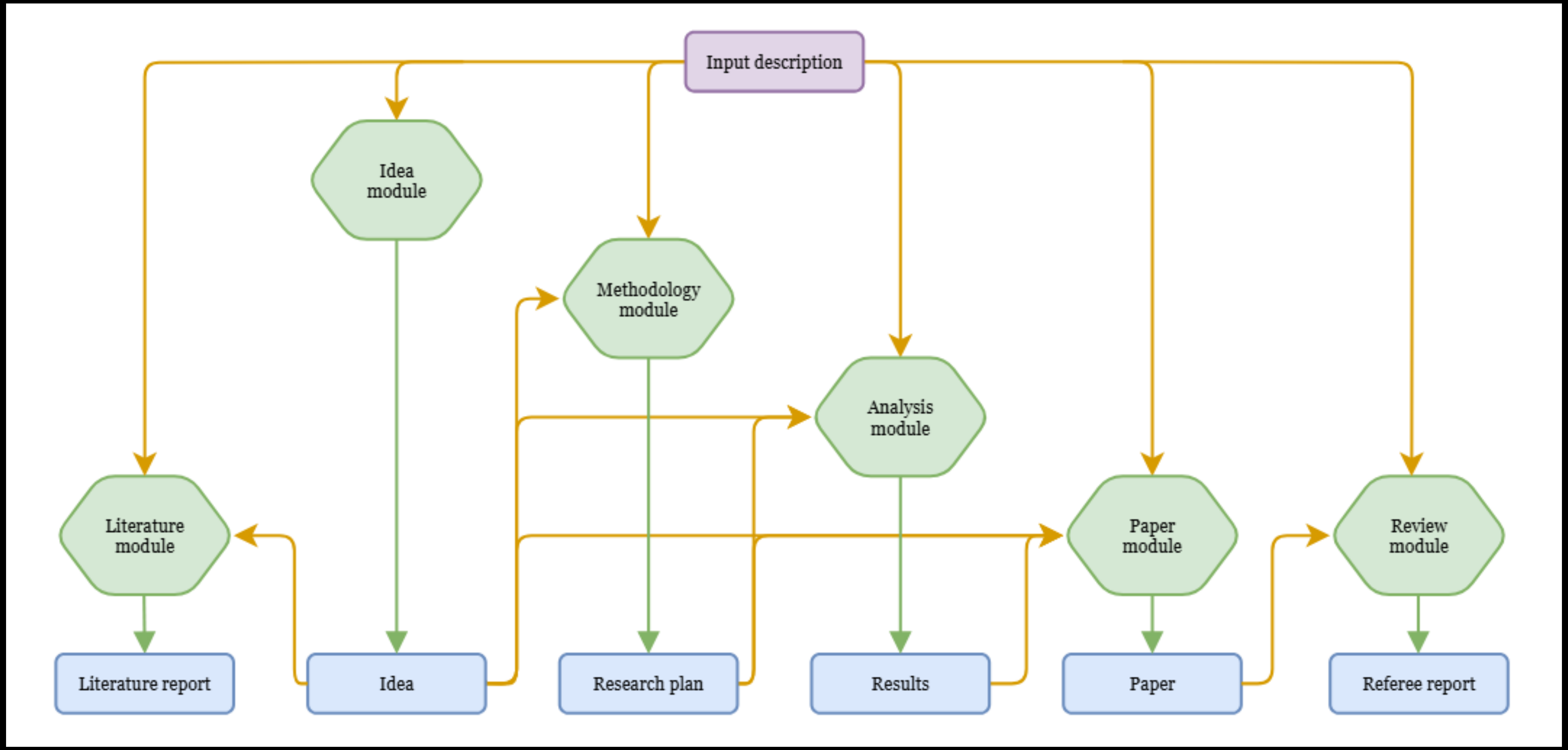
DENARIO: The Architecture

- **Methodology module:** Takes **input.md** and **idea.md** and will produce **methods.md**
- Goal: produce plan and methodology to tackle the problem
- The output will be a detailed research plan
- It will focus on the methods and workflow, rather than generating results



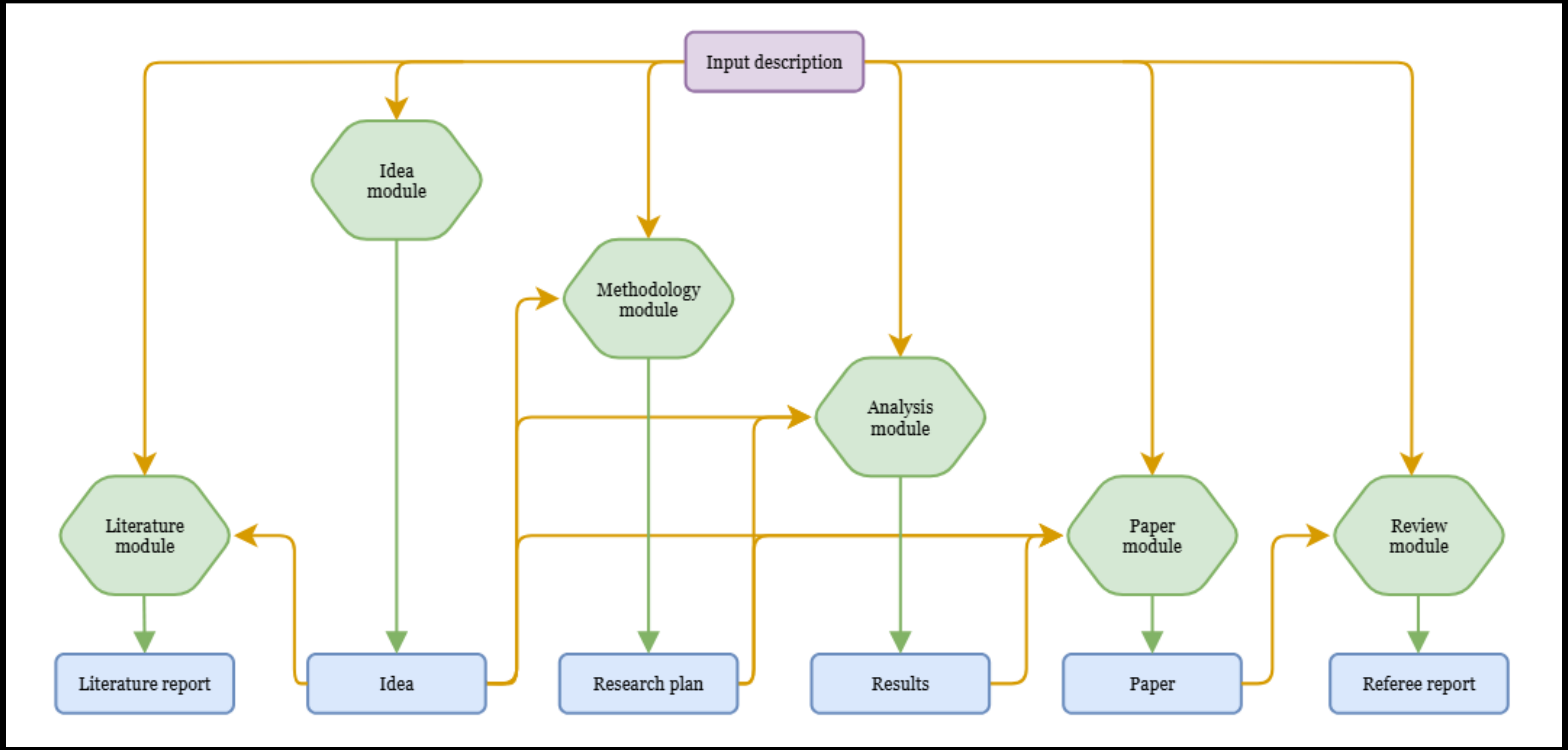
DENARIO: The Architecture

- **Analysis Module:** Takes **input.md**, **idea.md** and **methods.md**.



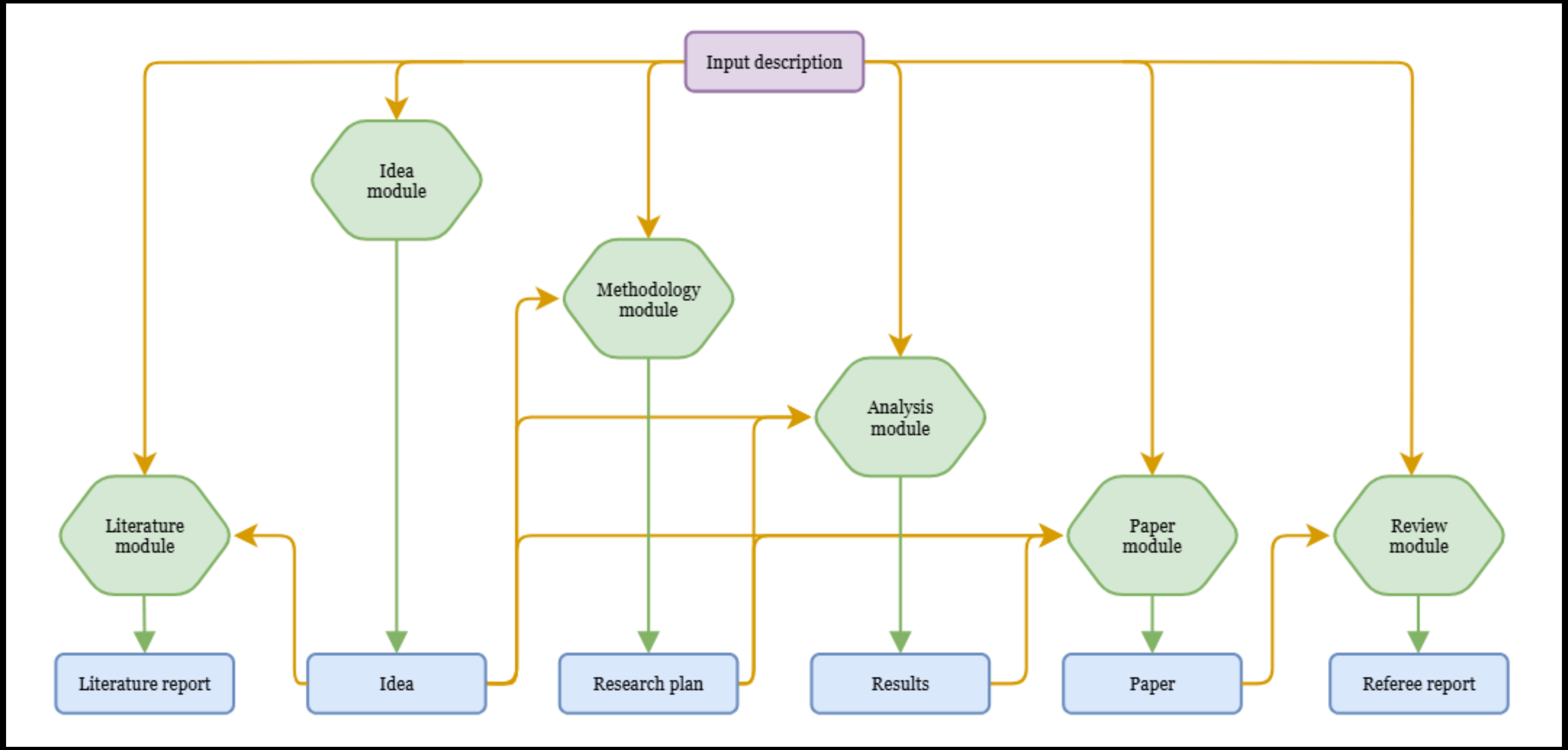
DENARIO: The Architecture

- **Analysis Module:** Takes **input.md**, **idea.md** and **methods.md**.
- Goal: generate the results as stated in the methodology



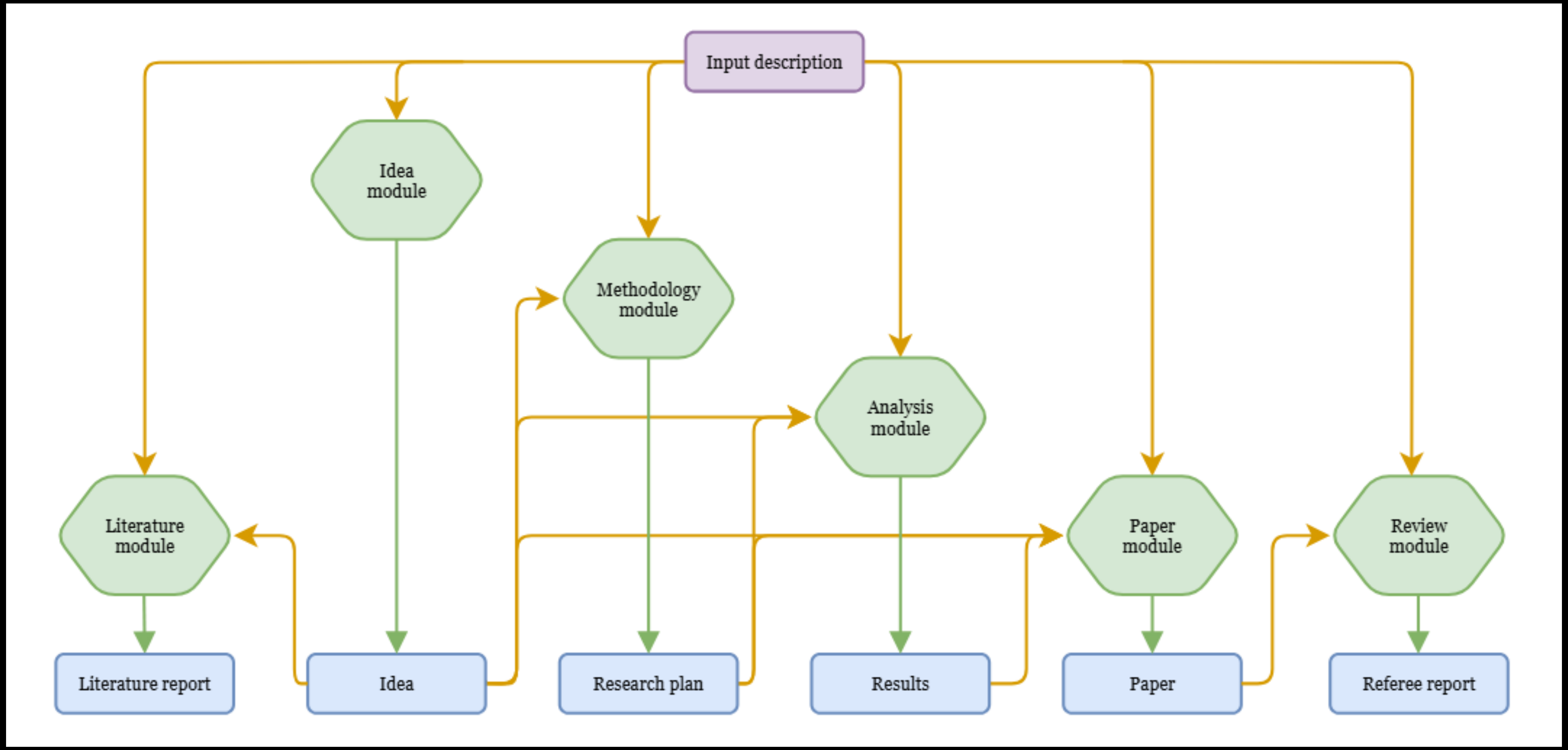
DENARIO: The Architecture

- **Analysis Module:** Takes **input.md**, **idea.md** and **methods.md**.
- Goal: generate the results as stated in the methodology
- It can write and run code, generate plots and interpret the results



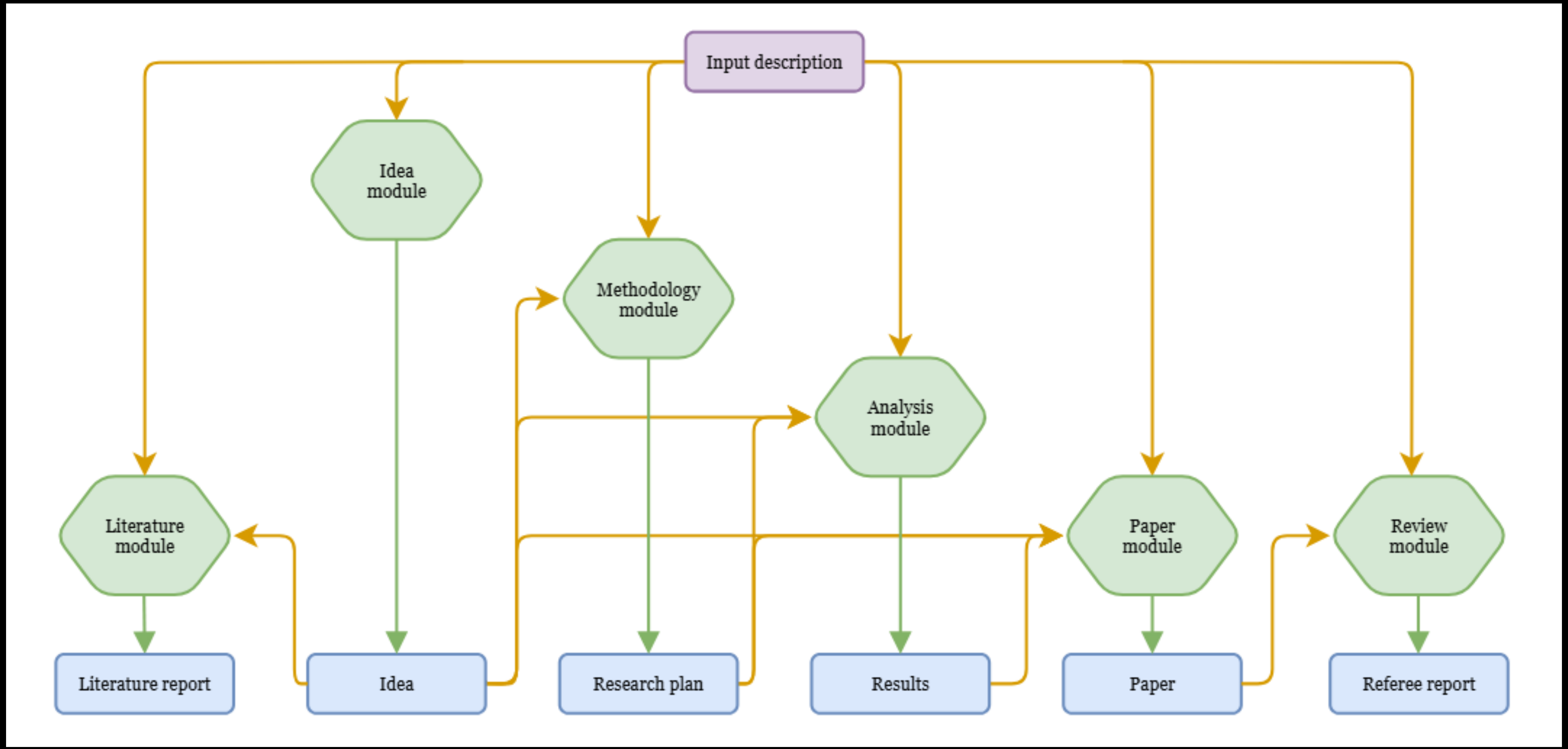
DENARIO: The Architecture

- **Analysis Module:** Takes **input.md**, **idea.md** and **methods.md**.
- Goal: generate the results as stated in the methodology
- It can write and run code, generate plots and interpret the results
- The output will be a **report** and **plots**



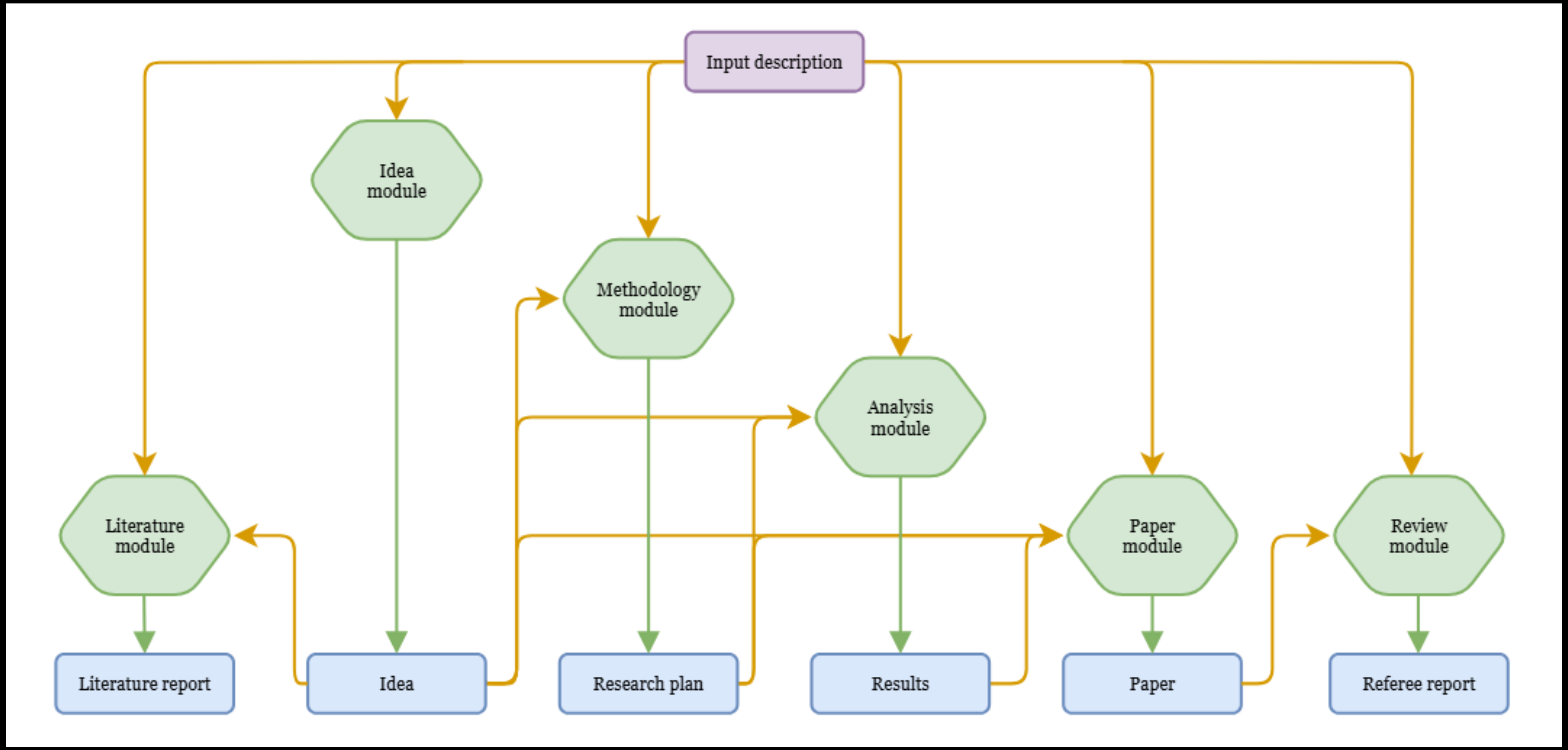
DENARIO: The Architecture

- **Analysis Module:** Takes **input.md**, **idea.md** and **methods.md**.
- Goal: generate the results as stated in the methodology
- It can write and run code, generate plots and interpret the results
- The output will be a **report** and **plots**
- Framed out in research-specialized **cmbagent**



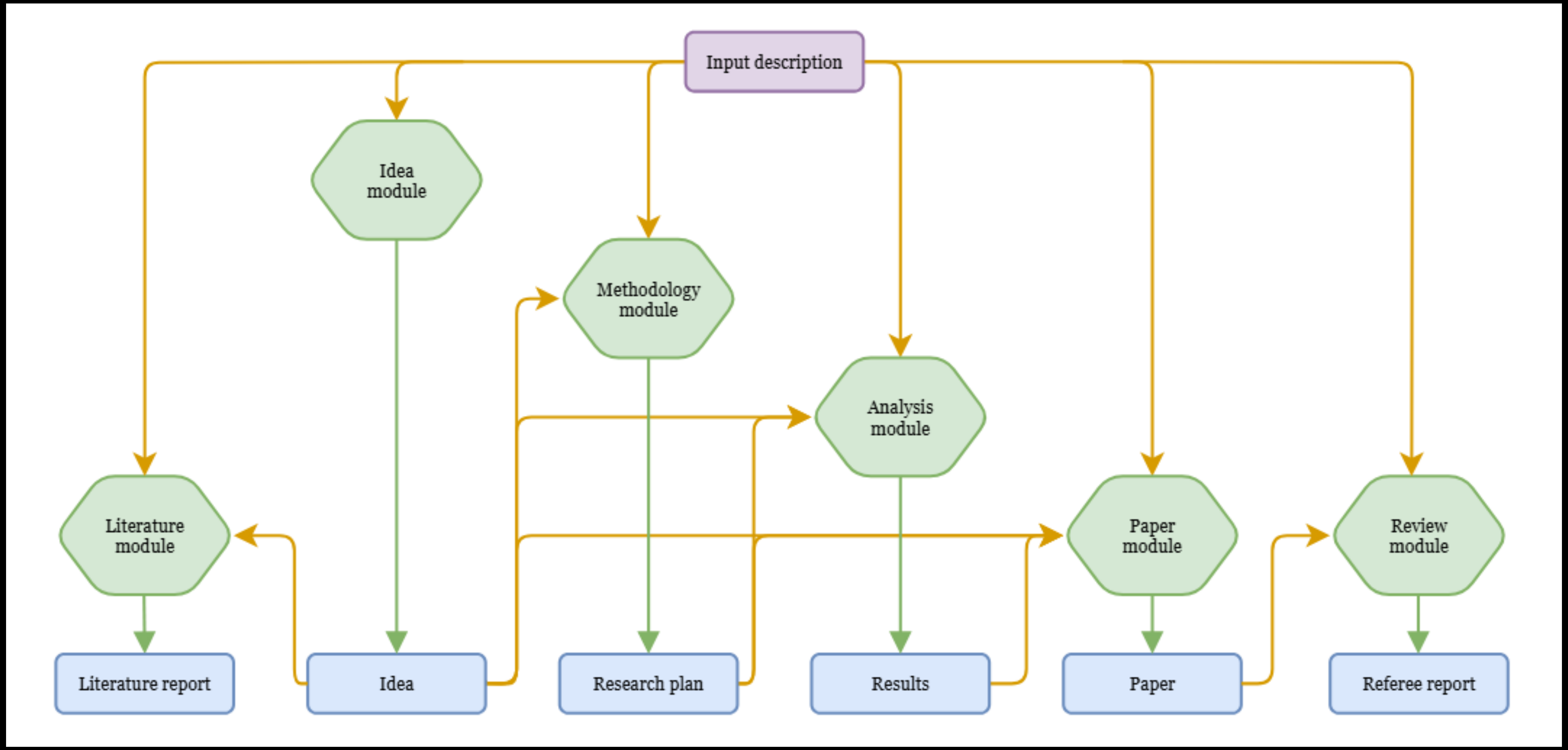
DENARIO: The Architecture

- **Report Module:** Takes **input.md**, **idea.md**, **methods.md** and **results.md**



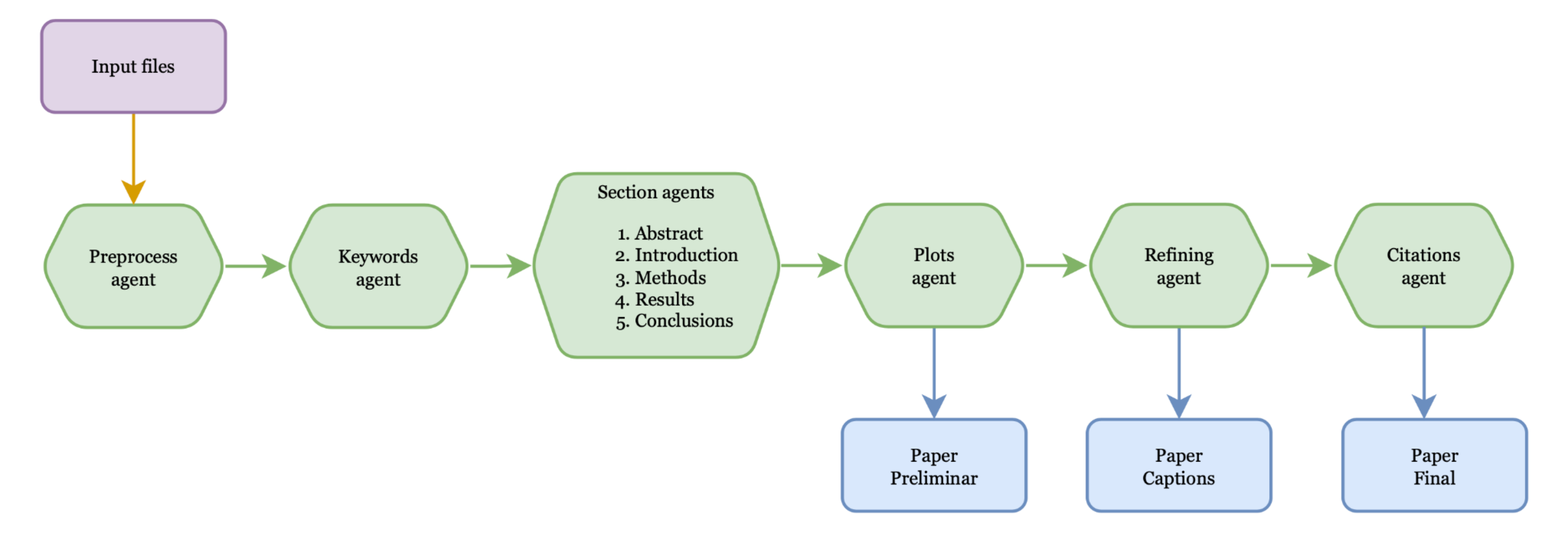
DENARIO: The Architecture

- **Report Module:** Takes **input.md**, **idea.md**, **methods.md** and **results.md**
- Goal: put everything together and write the report



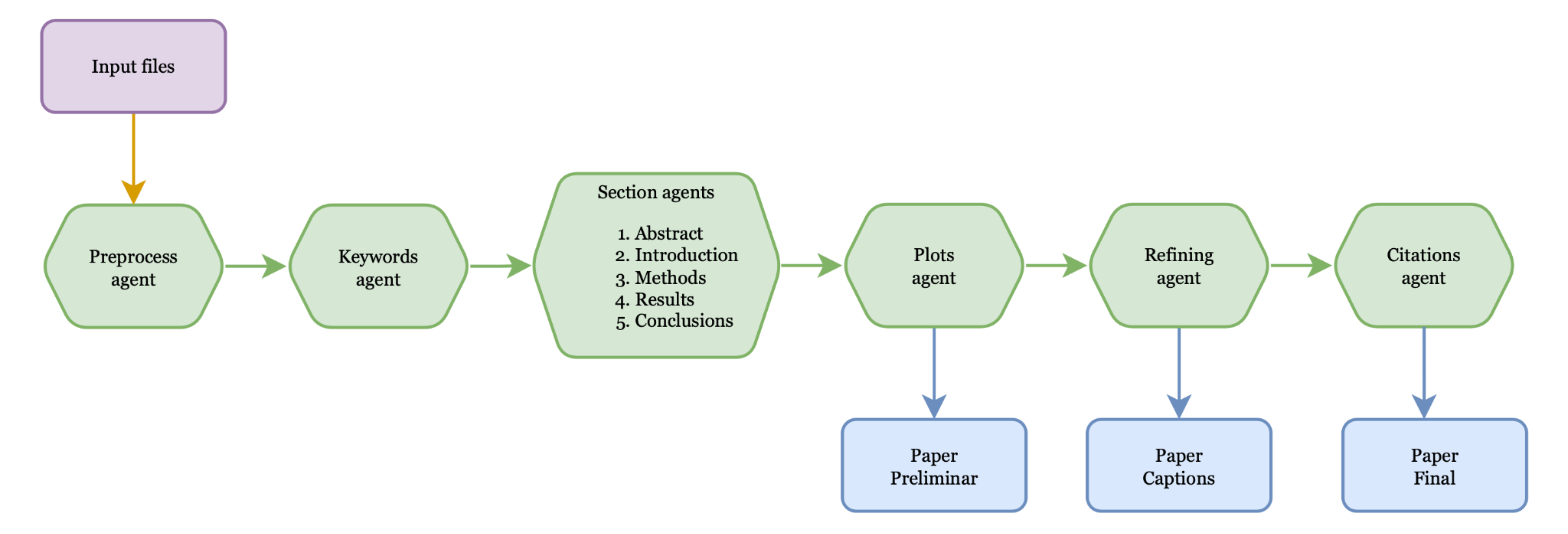
DENARIO: The Architecture

- **Report Module:** Takes **input.md**, **idea.md**, **methods.md** and **results.md**
- Goal: put everything together and write the report
- Different agents will take care of different abstract/sections/plots.



DENARIO: The Architecture

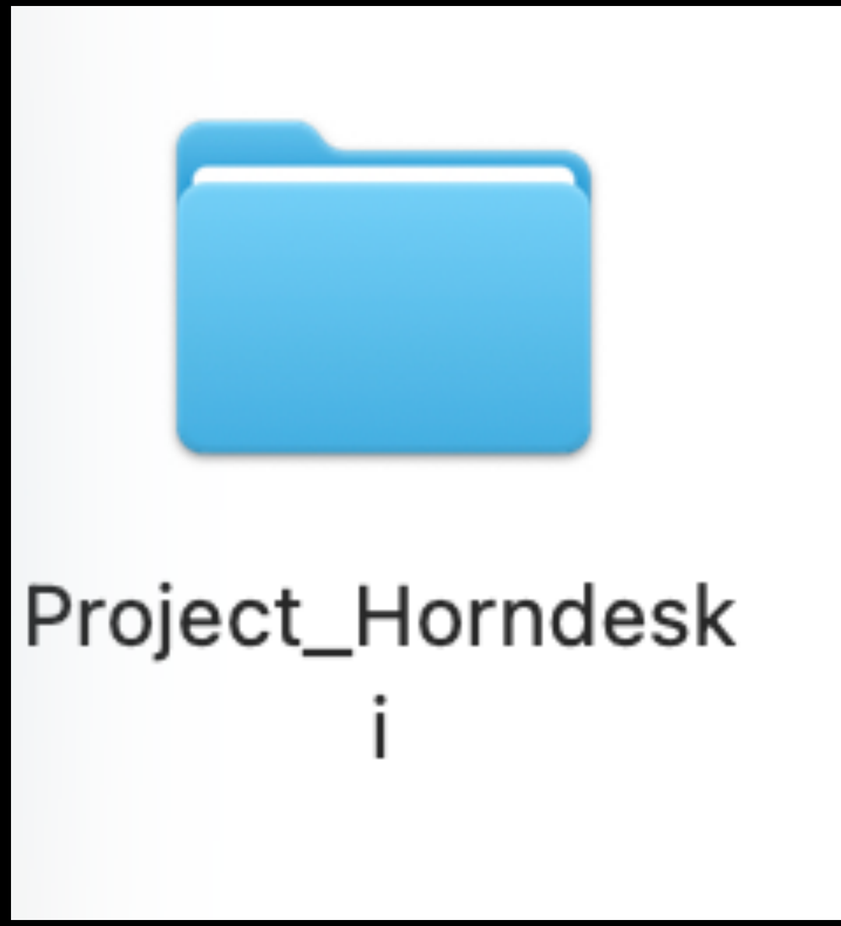
- **Report Module:** Takes **input.md**, **idea.md**, **methods.md** and **results.md**
- Goal: put everything together and write the report
- Different agents will take care of different abstract/sections/plots.
- The output will be a .tex file with the final report.



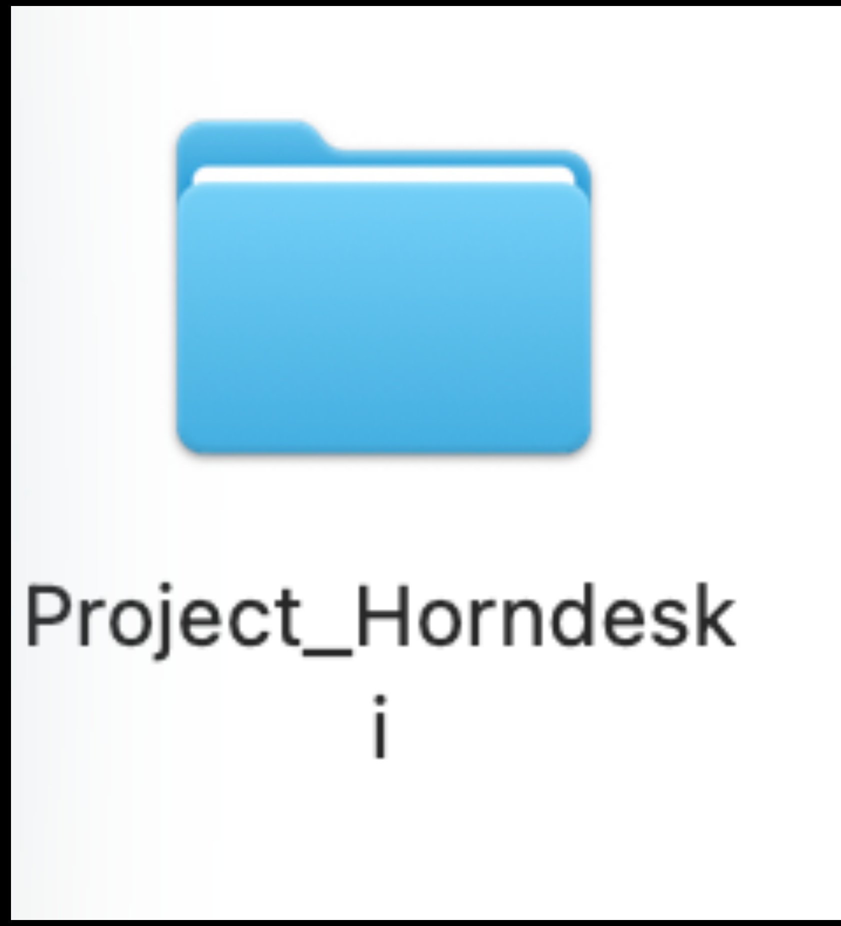
DENARIO: What you obtain

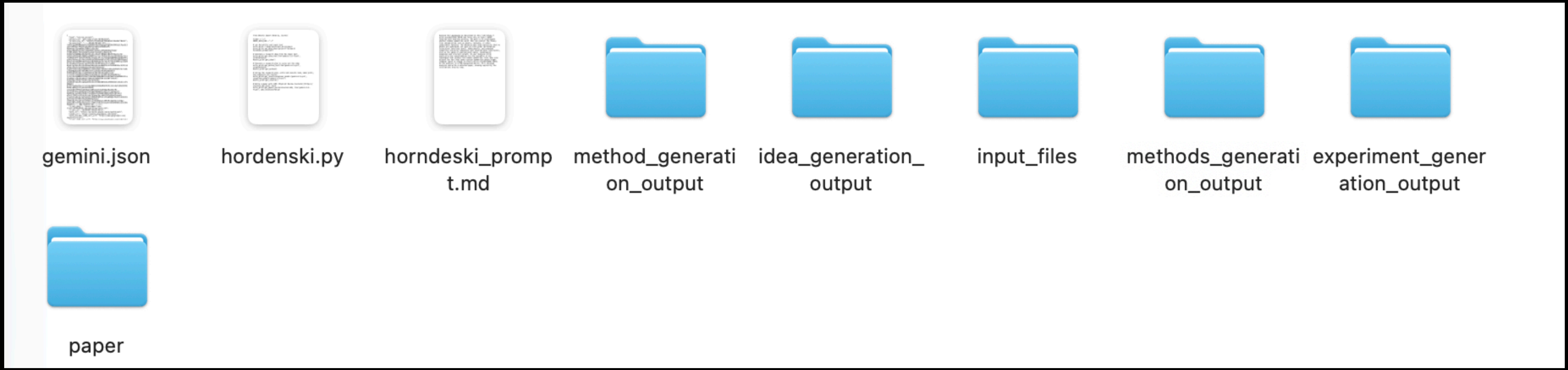
DENARIO: What you obtain

DENARIO: What you obtain



DENARIO: What you obtain





The Physical set up

Theories of modified gravity: scalar tensor theories

$$\mathcal{L} = \mathcal{L}_{EH} + \mathcal{L}_{\phi}$$

The Physical set up

Theories of modified gravity: scalar tensor theories

$$\mathcal{L} = \mathcal{L}_{EH} + \mathcal{L}_{\phi}$$

Horndeski theories (1974): most general tensor-scalar with 2° EOMs + Galilean symmetry for the scalar dof → Galileons

The Physical set up

Theories of modified gravity: scalar tensor theories

$$\mathcal{L} = \mathcal{L}_{EH} + \mathcal{L}_{\phi}$$

Horndeski theories (1974): most general tensor-scalar with 2° EOMs + Galilean symmetry for the scalar dof → Galileons

Ostrogadsky theorem: *Any non-degenerate Lagrangian that depends non-trivially on time derivatives higher than first order leads to a Hamiltonian that is linear in at least one canonical momentum and is therefore unbounded from below. Consequently, the theory possesses an instability, known as the Ostrogradsky instability or Ostrogradsky ghost.*

The Physical set up

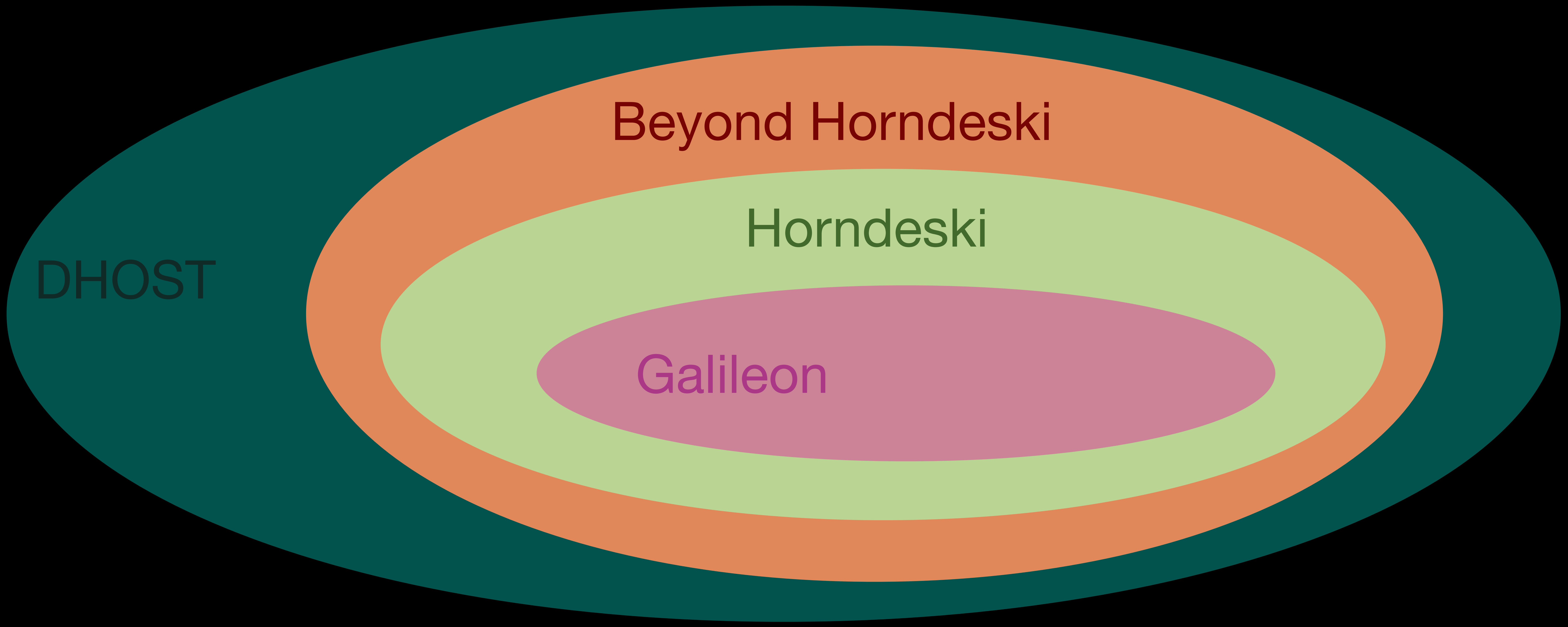
DHOST theories: Degenerate higher order scalar tensor theories

$$\delta S = 0 \quad + \quad \det\left[\mathcal{K}\right] = 0$$

The Physical set up

DHOST theories: Degenerate higher order scalar tensor theories

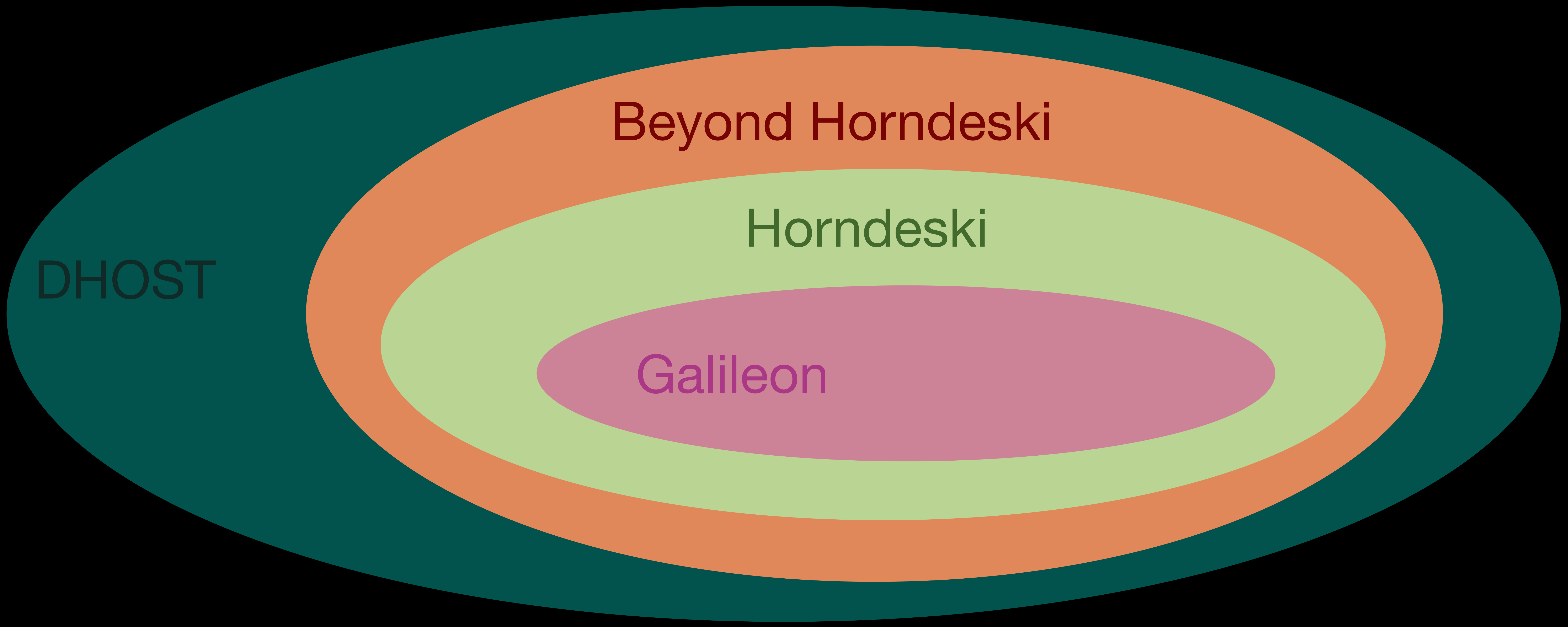
$$\delta S = 0 \quad + \quad \det\left[\mathcal{K}\right] = 0$$



The Physical set up

DHOST theories: Degenerate higher order scalar tensor theories

$$\delta S = 0 \quad + \quad \det\left[\mathcal{K}\right] = 0$$



DHOST: most general scalar tensor theories

The Physical set up

Degeneracy conditions → Constraints on the parameters of your theory

$$S[g_{\mu\nu}, \phi] = \int d^4x \sqrt{-g} \, [F(X, \phi) R + C^{\mu\nu,\rho\sigma} \nabla_\mu \nabla_\nu \phi \nabla_\rho \nabla_\sigma \phi]$$

The Physical set up

Degeneracy conditions → Constraints on the parameters of your theory

$$S[g_{\mu\nu},\phi] = \int d^4x\,\sqrt{-g}\,[F(X,\phi)R + C^{\mu\nu,\rho\sigma}\nabla_\mu\nabla_\nu\phi\nabla_\rho\nabla_\sigma\phi]$$

$$\downarrow$$

$$C^{\mu\nu,\rho\sigma} \propto \sum_{i=1}^{5} A_i\,(X,\phi)$$

The Physical set up

Degeneracy conditions → Constraints on the parameters of your theory

$$S[g_{\mu\nu},\phi] = \int d^4x\,\sqrt{-g}\,[F(X,\phi)R + C^{\mu\nu,\rho\sigma}\nabla_\mu\nabla_\nu\phi\nabla_\rho\nabla_\sigma\phi]$$

$$\downarrow$$

$$C^{\mu\nu,\rho\sigma} \propto \sum_{i=1}^{5} A_i\,(X,\phi)$$

Stable theory on the classical level. What happens when we consider quantum corrections?

The Physical set up

Stable theory on the classical level. What happens when we consider quantum corrections?

The Physical set up

Stable theory on the classical level. What happens when we consider quantum corrections?

- Galileon theories → Non renormalization theorem: *quantum loop corrections do not renormalize the coefficients of the Galileon operators. Loops may generate operators with more derivatives per field, but they cannot change the coefficients of the original Galileon interactions.*

The Physical set up

Stable theory on the classical level. What happens when we consider quantum corrections?

- Galileon theories → Non renormalization theorem: *quantum loop corrections do not renormalize the coefficients of the Galileon operators. Loops may generate operators with more derivatives per field, but they cannot change the coefficients of the original Galileon interactions.*

- DHOST theories → Do we have a mechanism that can guarantee stability when we consider loops?

AI-Assisted Exploration

QUESTION: Can we see these constraints as a manifestation of a hidden symmetry?

AI-Assisted Exploration

QUESTION: Can we see these constraints as a manifestation of a hidden symmetry?

```
Analyse the Horndeski Lagrangian as described here https://arxiv.org/abs/1404.3713. The goal is to
investigate whether hidden symmetries exist that can protect the theory from instabilities such as ghosts,
tachyons, or other undesirable features. The analysis must show explicitly that no ghosts are generated,
not even at first-order perturbative corrections (one-loop level). Additionally, any proposed symmetries
should be compatible with observational constraints, such as the speed of gravitational waves,
cosmological expansion and structure growth. Do a thorough analysis and write a detailed paper.
```

AI-Assisted Exploration

QUESTION: Can we see these constraints as a manifestation of a hidden symmetry?

```
Analyse the Horndeski Lagrangian as described here https://arxiv.org/abs/1404.3713. The goal is to
investigate whether hidden symmetries exist that can protect the theory from instabilities such as ghosts,
tachyons, or other undesirable features. The analysis must show explicitly that no ghosts are generated,
not even at first-order perturbative corrections (one-loop level). Additionally, any proposed symmetries
should be compatible with observational constraints, such as the speed of gravitational waves,
cosmological expansion and structure growth. Do a thorough analysis and write a detailed paper.
```

↓

AI-Assisted Exploration

Draft version September 26, 2025
Typeset using LaTeX **twocolumn** style in AASTeX631

Quantum Kinetic Structure Preservation in Horndeski Theories: Ensuring One-Loop Stability and Testable Cosmology

Denario[1]

[1] *Anthropic, Gemini & OpenAI servers. Planet Earth.*

ABSTRACT

Horndeski theories, while constructed to be classically ghost-free, face the critical challenge of preserving this stability under quantum corrections, which often introduce problematic higher-derivative ghost terms into the effective action. This paper proposes the Quantum Kinetic Structure Preservation (QKSP) symmetry, a principle defined by specific algebraic and differential relations among the theory's functions, designed to explicitly maintain its intrinsic ghost-free kinetic structure at the one-loop level and prevent the generation of new propagating ghost degrees of freedom. Our multi-stage theoretical analysis first establishes classical stability conditions for Horndeski theories around a flat Friedmann-Lemaître-Robertson-Walker background, incorporating the observational constraint of luminal gravitational wave propagation ($c_T^2 = 1$). We then compute the one-loop effective action using the background field method and heat kernel regularization to identify quantum-generated higher-derivative terms. The QKSP conditions are derived by demanding the vanishing of coefficients for terms that would introduce higher-than-second-order time derivatives in the effective action for physical perturbations. We find that QKSP symmetry fundamentally implies that scalar and tensor modes must propagate at the same speed ($c_s^2 = c_T^2$), which, combined with the empirical $c_T^2 = 1$, leads to the strong prediction that QKSP-symmetric Horndeski theories must satisfy $c_s^2 = 1$. A sub-

AI-Assisted Exploration

DRAFT VERSION SEPTEMBER 26, 2025
Typeset using LATEX **twocolumn** style in AASTeX631

Quantum Kinetic Structure Preservation in Horndeski Theories: Ensuring One-Loop Stability and Testable Cosmology

DENARIO[1]

[1] *Anthropic, Gemini & OpenAI servers. Planet Earth.*

ABSTRACT

Horndeski theories, while constructed to be classically ghost-free, face the critical challenge of preserving this stability under quantum corrections, which often introduce problematic higher-derivative ghost terms into the effective action. This paper proposes the Quantum Kinetic Structure Preservation (QKSP) symmetry, a principle defined by specific algebraic and differential relations among the theory's functions, designed to explicitly maintain its intrinsic ghost-free kinetic structure at the one-loop level and prevent the generation of new propagating ghost degrees of freedom. Our multi-stage theoretical analysis first establishes classical stability conditions for Horndeski theories around a flat Friedmann-Lemaître-Robertson-Walker background, incorporating the observational constraint of luminal gravitational wave propagation ($c_T^2 = 1$). We then compute the one-loop effective action using the background field method and heat kernel regularization to identify quantum-generated higher-derivative terms. The QKSP conditions are derived by demanding the vanishing of coefficients for terms that would introduce higher-than-second-order time derivatives in the effective action for physical perturbations. We find that QKSP symmetry fundamentally implies that scalar and tensor modes must propagate at the same speed ($c_s^2 = c_T^2$), which, combined with the empirical $c_T^2 = 1$, leads to the strong prediction that QKSP-symmetric Horndeski theories must satisfy $c_s^2 = 1$. A sub-

paper_v2_no_citations.tex

AI-Assisted Exploration

Draft version September 26, 2025
Typeset using LaTeX **twocolumn** style in AASTeX631

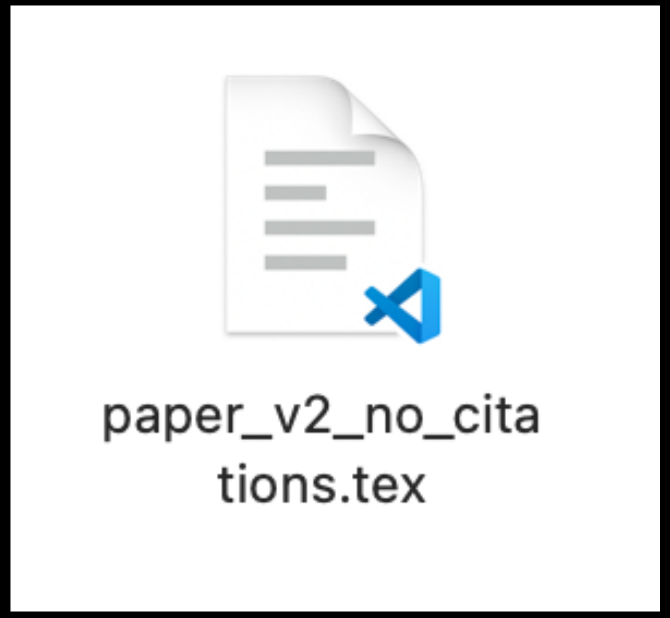
Quantum Kinetic Structure Preservation in Horndeski Theories: Ensuring One-Loop Stability and Testable Cosmology

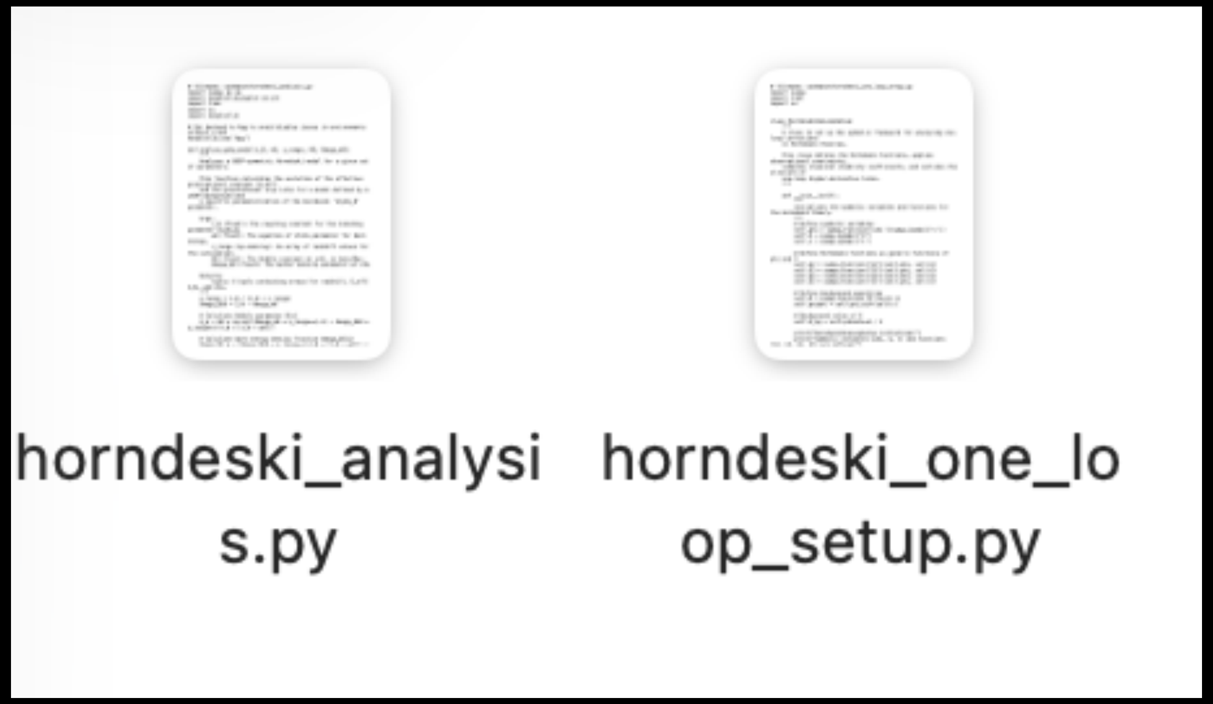
Denario[1]

[1] *Anthropic, Gemini & OpenAI servers. Planet Earth.*

ABSTRACT

Horndeski theories, while constructed to be classically ghost-free, face the critical challenge of preserving this stability under quantum corrections, which often introduce problematic higher-derivative ghost terms into the effective action. This paper proposes the Quantum Kinetic Structure Preservation (QKSP) symmetry, a principle defined by specific algebraic and differential relations among the theory's functions, designed to explicitly maintain its intrinsic ghost-free kinetic structure at the one-loop level and prevent the generation of new propagating ghost degrees of freedom. Our multi-stage theoretical analysis first establishes classical stability conditions for Horndeski theories around a flat Friedmann-Lemaître-Robertson-Walker background, incorporating the observational constraint of luminal gravitational wave propagation ($c_T^2 = 1$). We then compute the one-loop effective action using the background field method and heat kernel regularization to identify quantum-generated higher-derivative terms. The QKSP conditions are derived by demanding the vanishing of coefficients for terms that would introduce higher-than-second-order time derivatives in the effective action for physical perturbations. We find that QKSP symmetry fundamentally implies that scalar and tensor modes must propagate at the same speed ($c_s^2 = c_T^2$), which, combined with the empirical $c_T^2 = 1$, leads to the strong prediction that QKSP-symmetric Horndeski theories must satisfy $c_s^2 = 1$. A sub-





AI-Assisted Exploration

DRAFT VERSION SEPTEMBER 26, 2025
Typeset using LATEX **twocolumn** style in AASTeX631

Quantum Kinetic Structure Preservation in Horndeski Theories: Ensuring One-Loop Stability and Testable Cosmology

DENARIO[1]

[1] *Anthropic, Gemini & OpenAI servers. Planet Earth.*

ABSTRACT

Horndeski theories, while constructed to be classically ghost-free, face the critical challenge of preserving this stability under quantum corrections, which often introduce problematic higher-derivative ghost terms into the effective action. This paper proposes the Quantum Kinetic Structure Preservation (QKSP) symmetry, a principle defined by specific algebraic and differential relations among the theory's functions, designed to explicitly maintain its intrinsic ghost-free kinetic structure at the one-loop level and prevent the generation of new propagating ghost degrees of freedom. Our multi-stage theoretical analysis first establishes classical stability conditions for Horndeski theories around a flat Friedmann-Lemaître-Robertson-Walker background, incorporating the observational constraint of luminal gravitational wave propagation ($c_T^2 = 1$). We then compute the one-loop effective action using the background field method and heat kernel regularization to identify quantum-generated higher-derivative terms. The QKSP conditions are derived by demanding the vanishing of coefficients for terms that would introduce higher-than-second-order time derivatives in the effective action for physical perturbations. We find that QKSP symmetry fundamentally implies that scalar and tensor modes must propagate at the same speed ($c_s^2 = c_T^2$), which, combined with the empirical $c_T^2 = 1$, leads to the strong prediction that QKSP-symmetric Horndeski theories must satisfy $c_s^2 = 1$. A sub-

AI-Assisted Exploration

DENARIO first iteration: Consider Type Ia class

$$A_1 = -A_2, \qquad F + XA_2 \neq 0, \qquad \text{constraints on } A_3, A_4, A_5$$

AI-Assisted Exploration

DENARIO first iteration: Consider Type Ia class

$$A_1 = -A_2, \qquad F + XA_2 \neq 0, \qquad \text{constraints on } A_3, A_4, A_5$$

Find whether it exists an hidden symmetry for this theory for which the degeneracy conditions can be seen as a manifestation of a hidden symmetry, protecting the possible quantum corrections.

AI-Assisted Exploration

DENARIO first iteration: Consider Type Ia class

$$A_1 = -A_2, \qquad F + XA_2 \neq 0, \qquad \text{constraints on } A_3, A_4, A_5$$

Find whether it exists an hidden symmetry for this theory for which the degeneracy conditions can be seen as a manifestation of a hidden symmetry, protecting the possible quantum corrections.

$$\begin{cases} \delta_\epsilon \phi(x) = \epsilon(x)\, \Lambda(\phi, X) \\ \delta_\epsilon g_{\mu\nu}(x) = \epsilon(x)\, \mathcal{L}_\xi(g_{\mu\nu}) = \epsilon(x)\, (\nabla_\mu \xi_\nu + \nabla_\nu \xi_\mu) \end{cases} \qquad \rightarrow \qquad \xi^\mu = \alpha(\phi, X)\, \phi^\mu$$

AI-Assisted Exploration

DENARIO subsequent iterations:

$$\Lambda(\phi, X) = F - XA_1, \qquad \alpha(\phi, X) = -A_1 + \frac{2F_X(F - XA_1)}{A_1} \left(\text{corrections in } F_X\right)$$

AI-Assisted Exploration

DENARIO subsequent iterations:

$$\Lambda(\phi, X) = F - XA_1, \qquad \alpha(\phi, X) = -A_1 + \frac{2F_X(F - XA_1)}{A_1} \left(\text{corrections in } F_X\right)$$

Simplest possible scenario:

AI-Assisted Exploration

DENARIO subsequent iterations:

$$\Lambda(\phi, X) = F - XA_1, \qquad \alpha(\phi, X) = -A_1 + \frac{2F_X(F - XA_1)}{A_1} \left(\text{corrections in } F_X\right)$$

Simplest possible scenario:

$$F = c_0\,, A_1 = c_1\,, A_3 = 0\,, A_4 = \frac{-16Xc_1^3 + 12c_0c_1^2}{8(c_0 - c_1X)^2}\,, A_5 = \frac{c_1^3}{2(c_0 - c_1X)^2}$$

AI-Assisted Exploration

DENARIO subsequent iterations:

$$\Lambda(\phi, X) = F - XA_1, \qquad \alpha(\phi, X) = -A_1 + \frac{2F_X(F - XA_1)}{A_1} \left(\text{corrections in } F_X\right)$$

Simplest possible scenario:

$$F = c_0\,, A_1 = c_1\,, A_3 = 0\,, A_4 = \frac{-16Xc_1^3 + 12c_0c_1^2}{8(c_0 - c_1X)^2}\,, A_5 = \frac{c_1^3}{2(c_0 - c_1X)^2} \;\rightarrow \Lambda = c_0 - Xc_1\,, \qquad \alpha = -c_1$$

AI-Assisted Exploration

DENARIO subsequent iterations:

$$\Lambda(\phi, X) = F - XA_1, \qquad \alpha(\phi, X) = -A_1 + \frac{2F_X(F - XA_1)}{A_1} \left(\text{corrections in } F_X\right)$$

Simplest possible scenario:

$$F = c_0\,, A_1 = c_1\,, A_3 = 0\,, A_4 = \frac{-16Xc_1^3 + 12c_0c_1^2}{8(c_0 - c_1X)^2}\,, A_5 = \frac{c_1^3}{2(c_0 - c_1X)^2} \;\; \rightarrow \Lambda = c_0 - Xc_1\,, \qquad \alpha = -c_1$$

Security check: is the classical action really invariant under this symmetry?

$$\tilde{g}_{\mu\nu} \equiv c_0 g_{\mu\nu} - c_1\phi_\mu\phi_\nu$$

AI-Assisted Exploration

DENARIO subsequent iterations:

$$\Lambda(\phi, X) = F - XA_1, \qquad \alpha(\phi, X) = -A_1 + \frac{2F_X(F - XA_1)}{A_1} \left(\text{corrections in } F_X\right)$$

Simplest possible scenario:

$$F = c_0\,, A_1 = c_1\,, A_3 = 0\,, A_4 = \frac{-16Xc_1^3 + 12c_0c_1^2}{8(c_0 - c_1X)^2}\,, A_5 = \frac{c_1^3}{2(c_0 - c_1X)^2} \;\rightarrow \Lambda = c_0 - Xc_1\,, \qquad \alpha = -c_1$$

Security check: is the classical action really invariant under this symmetry?

$$\tilde{g}_{\mu\nu} \equiv c_0 g_{\mu\nu} - c_1 \phi_\mu \phi_\nu \qquad \longrightarrow \; \delta_\epsilon \tilde{S}[\tilde{g}] = 0$$

AI-Assisted Exploration

Consider the quantum corrected Lagrangian

$$Z = \int \mathcal{D}\phi\, \mathcal{D}g\, e^{i\, S_{\mathrm{cl}}[g,\phi] + i\, S_{\mathrm{gf}}[g,\phi] + i\, S_{\mathrm{ghost}}}$$

AI-Assisted Exploration

Consider the quantum corrected Lagrangian

$$Z = \int \mathcal{D}\phi\,\mathcal{D}g\, e^{i\,S_{\rm cl}[g,\phi]+i\,S_{\rm gf}[g,\phi]+i\,S_{\rm ghost}}$$

De Donder gauge + Unitary gauge → Disformal frame

$$Z = \left(\int \mathcal{D}\phi\,\delta(\varphi)\,M_\epsilon\right)\cdot\int \mathcal{D}\tilde{g}\, e^{i\,\tilde{S}_{\rm cl}[\tilde{g}]+i\,\tilde{S}_{\rm gf}[\tilde{g}]+i\,\tilde{S}_{\rm ghost}}$$

AI-Assisted Exploration

Consider the quantum corrected Lagrangian

$$Z = \int \mathcal{D}\phi \, \mathcal{D}g \, e^{i\, S_{\rm cl}[g,\phi] + i\, S_{\rm gf}[g,\phi] + i\, S_{\rm ghost}}$$

De Donder gauge + Unitary gauge → Disformal frame

$$Z = \left(\int \mathcal{D}\phi \, \delta(\varphi) \, M_\epsilon \right) \cdot \int \mathcal{D}\tilde{g} \, e^{i\, \tilde{S}_{\rm cl}[\tilde{g}] + i\, \tilde{S}_{\rm gf}[\tilde{g}] + i\, \tilde{S}_{\rm ghost}}$$

↓

Pure gravity

AI-Assisted Exploration

Consider the quantum corrected Lagrangian

$$Z = \int \mathcal{D}\phi\, \mathcal{D}g\, e^{i\, S_{\rm cl}[g,\phi] + i\, S_{\rm gf}[g,\phi] + i\, S_{\rm ghost}}$$

De Donder gauge + Unitary gauge → Disformal frame

$$Z = \left(\int \mathcal{D}\phi\, \delta(\varphi)\, M_\epsilon \right) \cdot \int \mathcal{D}\tilde{g}\, e^{i\, \tilde{S}_{\rm cl}[\tilde{g}] + i\, \tilde{S}_{\rm gf}[\tilde{g}] + i\, \tilde{S}_{\rm ghost}}$$

↓ *Finite normalization*

↓ *Pure gravity*

AI-Assisted Exploration

Consider the quantum corrected Lagrangian

$$Z = \int \mathcal{D}\phi\, \mathcal{D}g\, e^{i\, S_{\mathrm{cl}}[g,\phi] + i\, S_{\mathrm{gf}}[g,\phi] + i\, S_{\mathbf{ghost}}}$$

De Donder gauge + Unitary gauge → Disformal frame

$$Z = \left(\int \mathcal{D}\phi\, \delta(\varphi)\, M_\epsilon \right) \cdot \int \mathcal{D}\tilde{g}\, e^{i\, \tilde{S}_{\mathrm{cl}}[\tilde{g}] + i\, \tilde{S}_{\mathrm{gf}}[\tilde{g}] + i\, \tilde{S}_{\mathbf{ghost}}}$$

↓ *Finite normalization*

↓ *Pure gravity*

Divergent part of the one loop effective action: Seeley-DeWitt coefficient

AI-Assisted Exploration

Seeley-DeWitt: $a_2 \propto \left\{ \tilde{R}, \tilde{G}, \tilde{W} \right\}$

AI-Assisted Exploration

Seeley-DeWitt: $a_2 \propto \left\{ \tilde{R}, \tilde{G}, \tilde{W} \right\}$

Going back to the original coordinates:

$$\mathcal{L}_{\rm ct} \simeq \left\{ \beta_W(c_0, c_1, X)\, W + \beta_G(c_0, c_1, X)\, G + \beta_R(c_0, c_1, X)\, R^2 + \sum_i \gamma_i(c_0, c_1, X)\, \mathcal{O}_i \right\}$$

AI-Assisted Exploration

Seeley-DeWitt: $a_2 \propto \left\{ \tilde{R}, \tilde{G}, \tilde{W} \right\}$

Going back to the original coordinates:

$$\mathcal{L}_{\rm ct} \simeq \left\{ \beta_W(c_0, c_1, X)\, W + \beta_G(c_0, c_1, X)\, G + \beta_R(c_0, c_1, X)\, R^2 + \sum_i \gamma_i(c_0, c_1, X)\, \mathcal{O}_i \right\}$$

Safe from Ostrogadsky ghost: Pure gravity theory → the scalar dof is not propagating

AI-Assisted Exploration

Seeley-DeWitt: $a_2 \propto \left\{\tilde{R}, \tilde{G}, \tilde{W}\right\}$

Going back to the original coordinates:

$$\mathcal{L}_{\rm ct} \simeq \left\{ \beta_W(c_0, c_1, X)\, W + \beta_G(c_0, c_1, X)\, G + \beta_R(c_0, c_1, X)\, R^2 + \sum_i \gamma_i(c_0, c_1, X)\, \mathcal{O}_i \right\}$$

Safe from Ostrogadsky ghost: Pure gravity theory → the scalar dof is not propagating

What happens with other gauge choices?

AI-Assisted Exploration

De Donder gauge + covariant gauge choice for the scalar field

AI-Assisted Exploration

De Donder gauge + covariant gauge choice for the scalar field

Expand the action up to second order in the fields

AI-Assisted Exploration

De Donder gauge + covariant gauge choice for the scalar field

Expand the action up to second order in the fields

Counterterms Lagrangian:

$$\mathcal{L}_{\rm ct} = \sqrt{-\bar{g}} \sum_i \mathcal{F}_i(\bar{\phi}, \bar{X})\, \mathcal{O}_i \simeq \{\text{Gravity} + \text{Interaction} + \text{Scalar}\}$$

AI-Assisted Exploration

De Donder gauge + covariant gauge choice for the scalar field

Expand the action up to second order in the fields

Counterterms Lagrangian:

$$\mathcal{L}_{\rm ct} = \sqrt{-\bar{g}} \sum_i \mathcal{F}_i(\bar{\phi}, \bar{X})\, \mathcal{O}_i \simeq \{\text{Gravity} + \text{Interaction} + \text{Scalar}\}$$

The gauge generator defines one of the null directions of the kinetic matrix

AI-Assisted Exploration

De Donder gauge + covariant gauge choice for the scalar field

Expand the action up to second order in the fields

Counterterms Lagrangian:

$$\mathcal{L}_{\rm ct} = \sqrt{-\bar{g}} \sum_i \mathcal{F}_i(\bar{\phi}, \bar{X})\, \mathcal{O}_i \simeq \{\text{Gravity} + \text{Interaction} + \text{Scalar}\}$$

The gauge generator defines one of the null directions of the kinetic matrix

Safe from Ostrogadsky ghost: gauge symmetry preserves degeneracy conditions

AI-Assisted Exploration

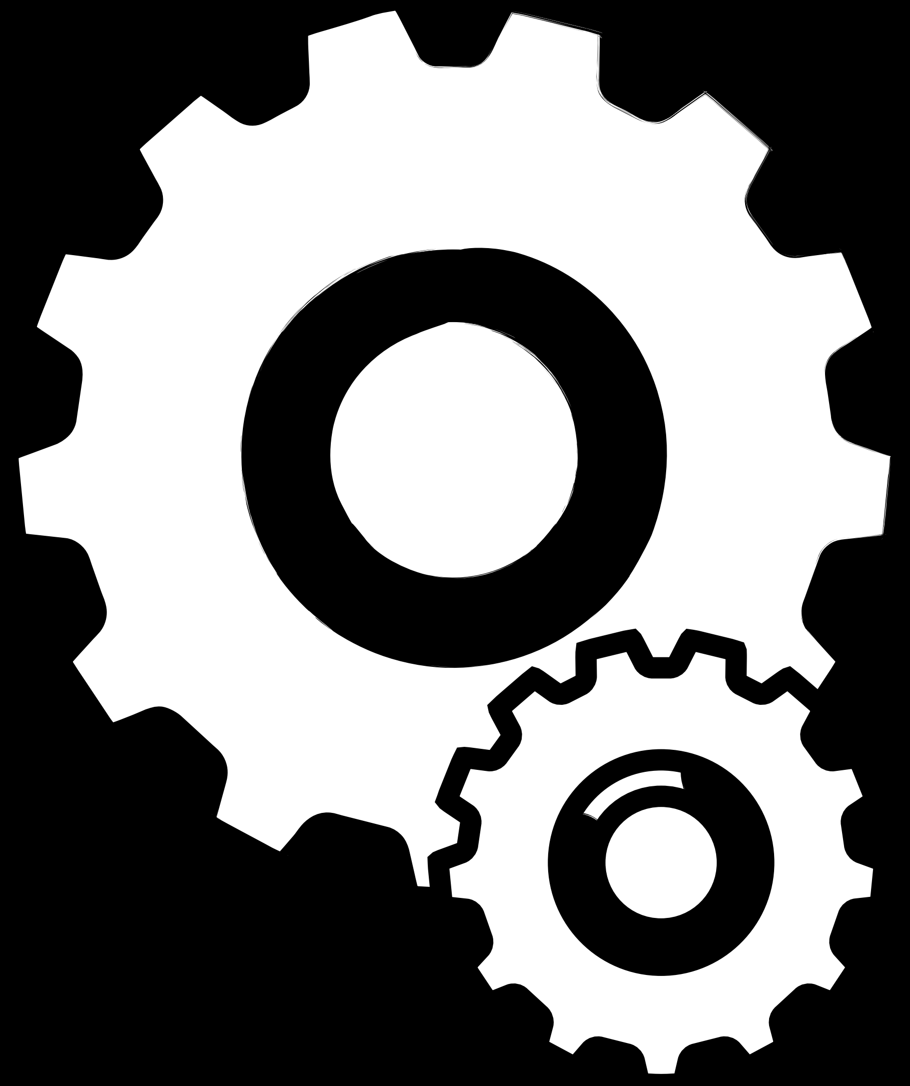
What about the other ghosts and instabilities?

$$\mathcal{L}_{\rm ct} = \sqrt{-\bar{g}} \sum_i \mathcal{F}_i(\bar{\phi}, \bar{X})\, \mathcal{O}_i \simeq \{\text{Gravity} + \text{Interaction} + \text{Scalar}\}$$

AI-Assisted Exploration

What about the other ghosts and instabilities?

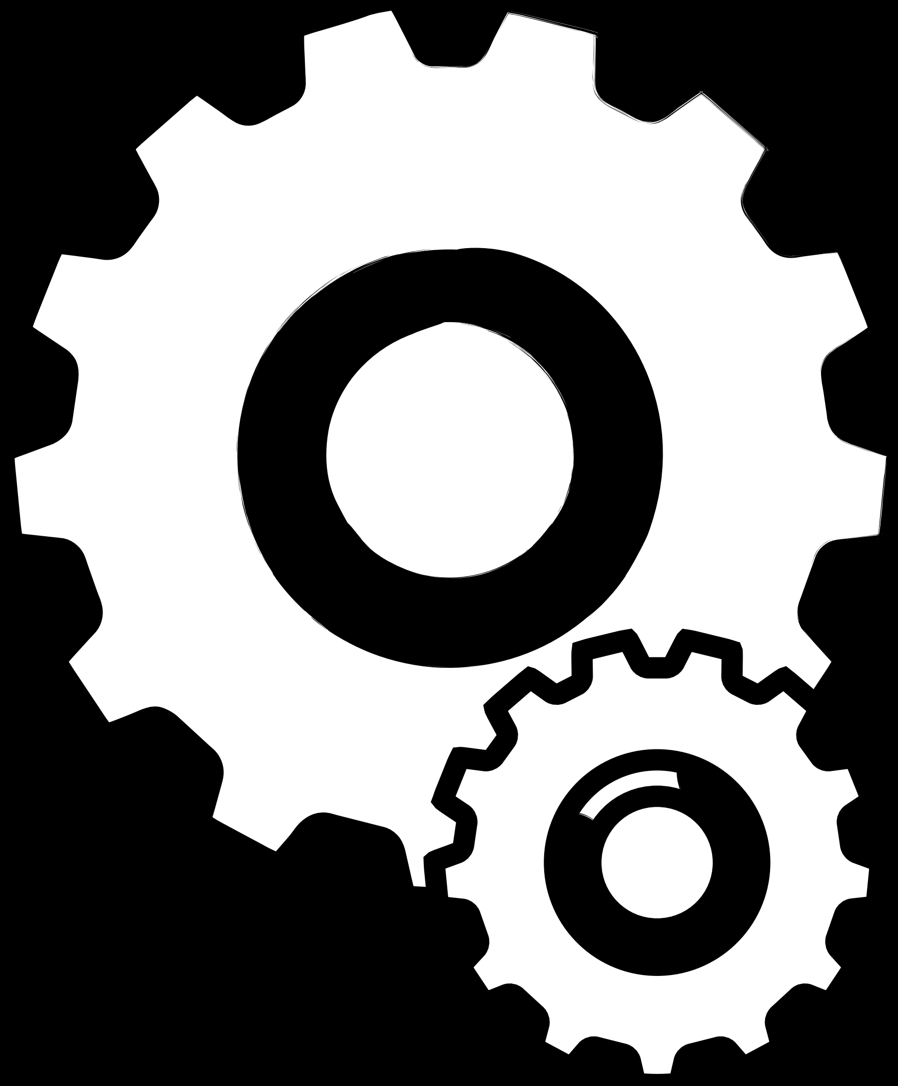
$$\mathcal{L}_{\rm ct} = \sqrt{-\bar{g}} \sum_i \mathcal{F}_i(\bar{\phi}, \bar{X})\, \mathcal{O}_i \simeq \{\text{Gravity} + \text{Interaction} + \text{Scalar}\}$$



AI-Assisted Exploration

What about the other ghosts and instabilities?

$$\mathcal{L}_{\rm ct} = \sqrt{-\bar{g}}\sum_i \mathcal{F}_i(\bar{\phi}, \bar{X})\, \mathcal{O}_i \simeq \{\text{Gravity} + \text{Interaction} + \text{Scalar}\}$$



EFT approach?

PROs & CONs

PROs & CONs

✓ More efficient

PROs & CONs

- ✓ More efficient
- ✓ Able to deal with theoretical problems

PROs & CONs

- ✓ More efficient
- ✓ Able to deal with theoretical problems
- ✓ Can speed up research

PROs & CONs

✓ More efficient

✓ Able to deal with theoretical problems

✓ Can speed up research

❎ Not entirely free

PROs & CONs

✓ More efficient

✓ Able to deal with theoretical problems

✓ Can speed up research

❎ Not entirely free

❎ Can make mistakes

PROs & CONs

✓ More efficient

✓ Able to deal with theoretical problems

✓ Can speed up research

❌ Not entirely free

❌ Can make mistakes

❌ Power compromised dynamics in academia (?)