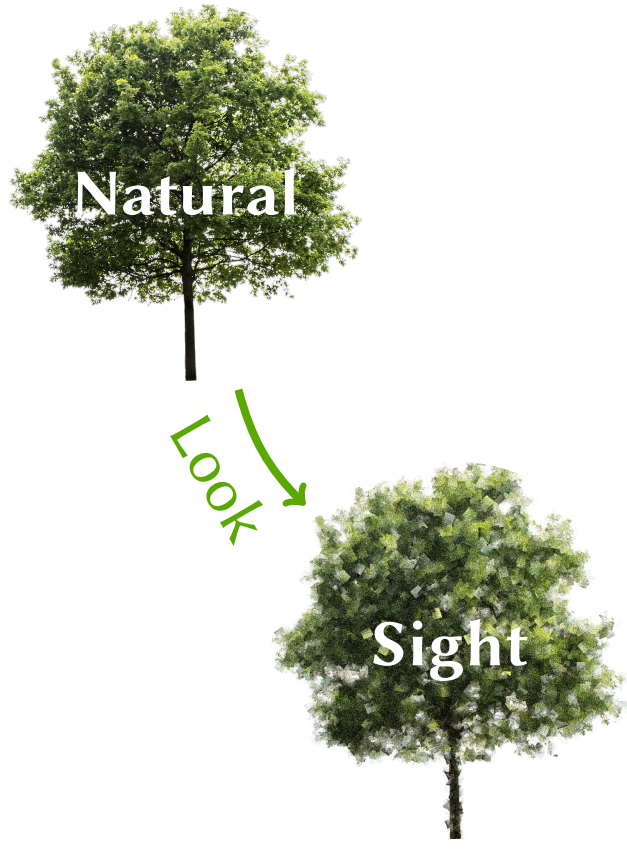
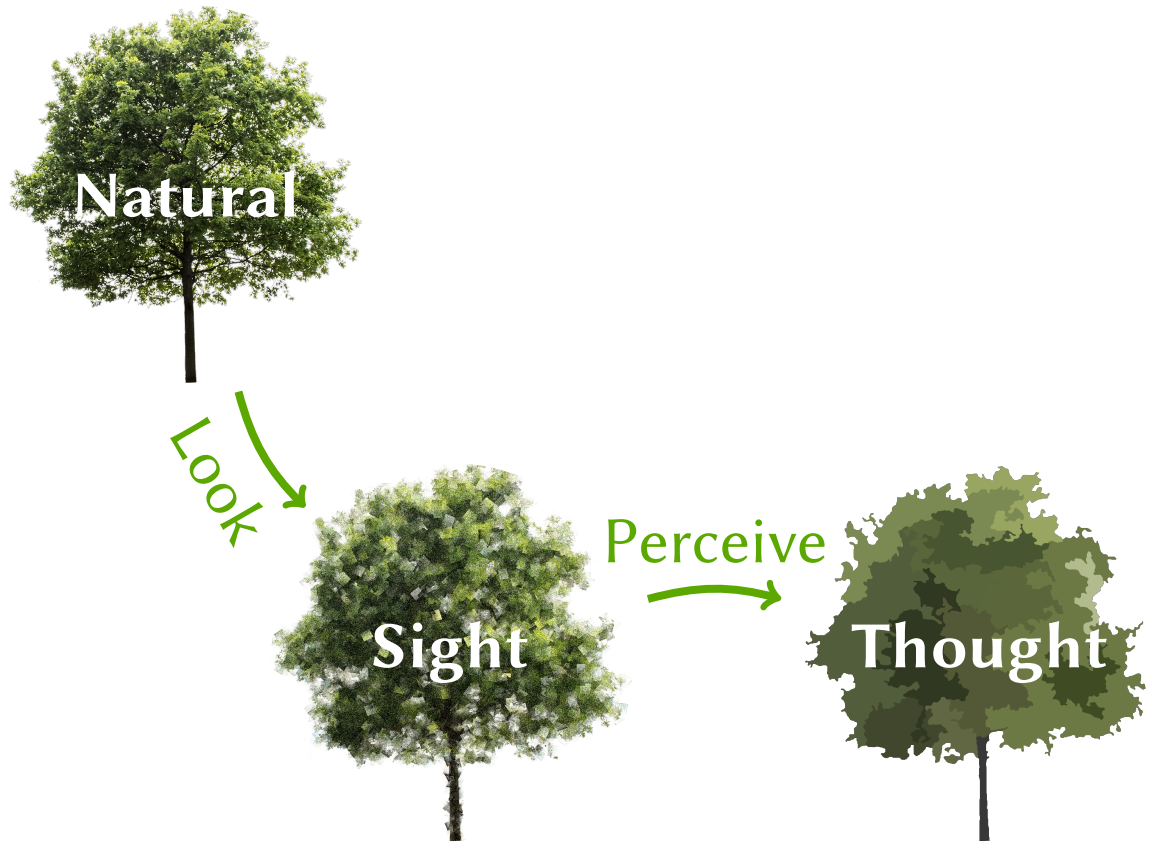
Physics REU: Summer 2020
Rensselaer Polytechnic Institute

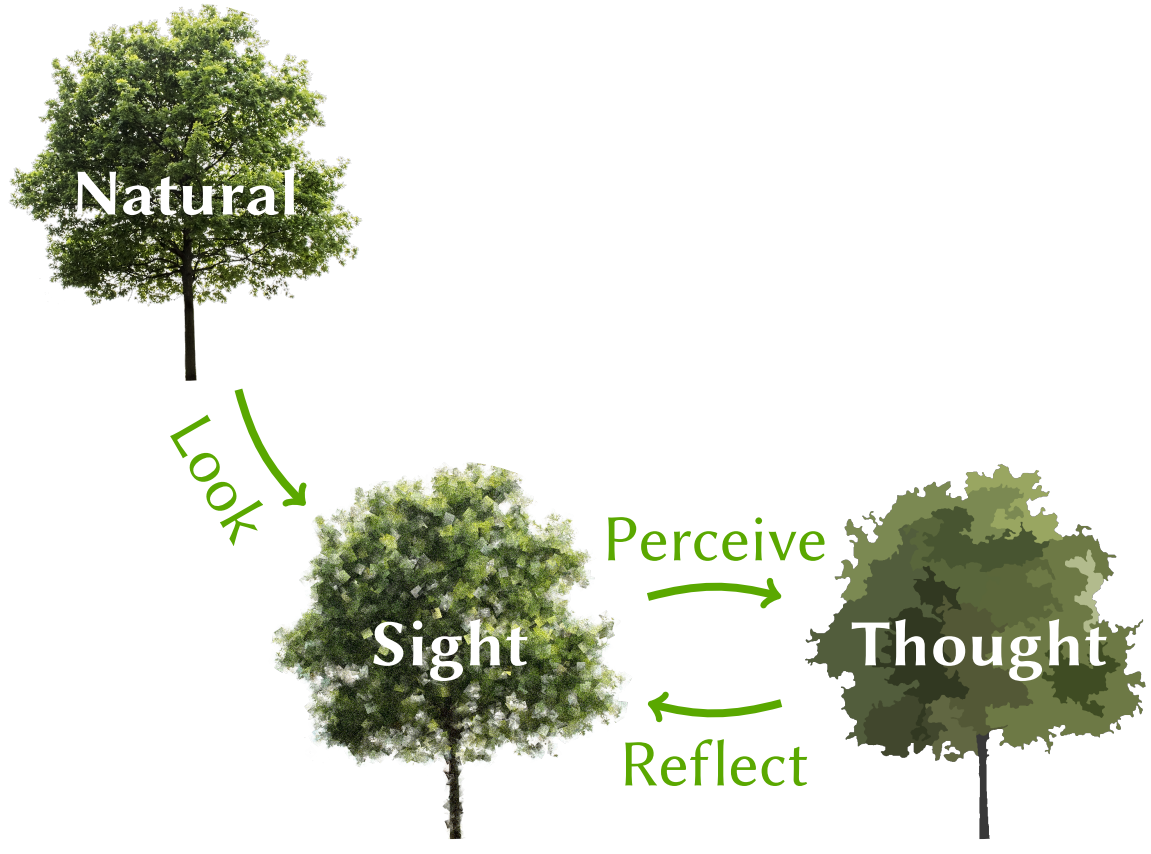
Understanding visual complexity with statistical physics

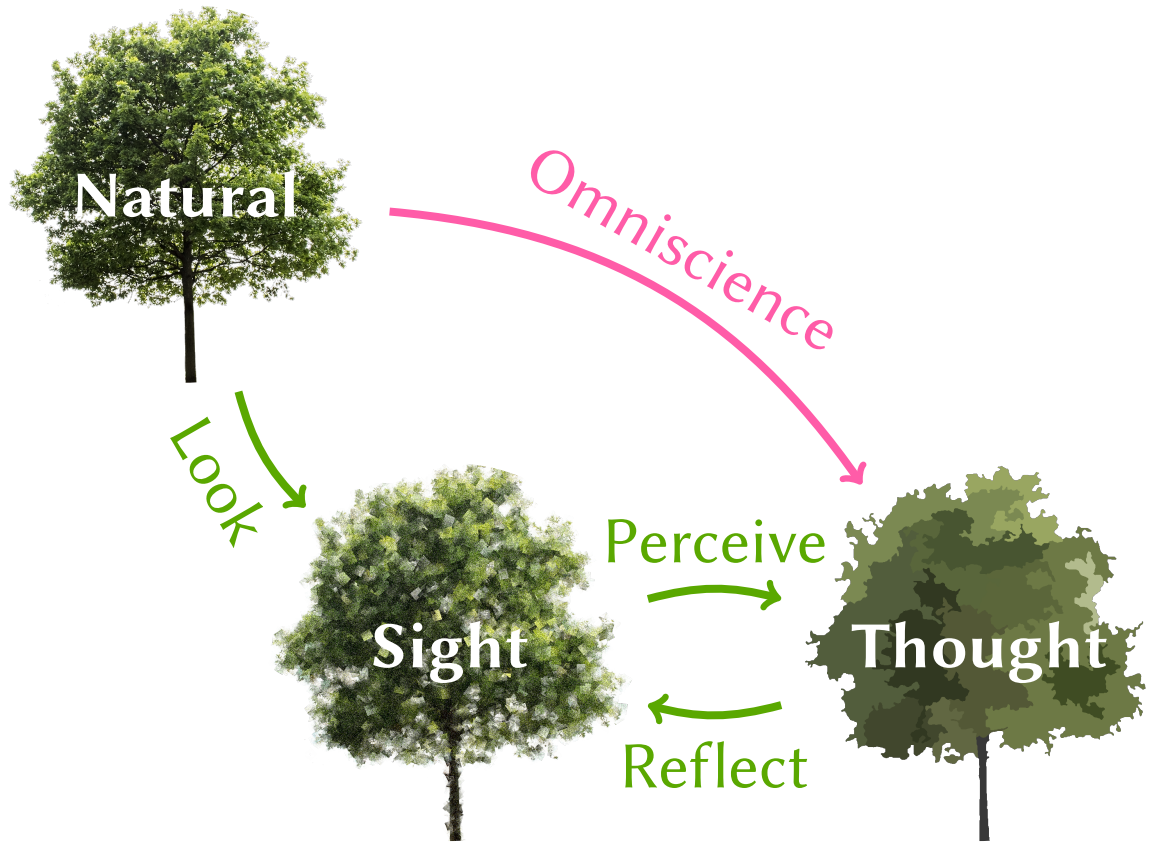
Alex Striff & Vincent Meunier


Natural


Natural
Look
Sight


Natural
Look
Sight
Perceive
Thought


Natural
Look
Sight
Perceive
Thought
Reflect


Natural
Omniscience
Look
Perceive
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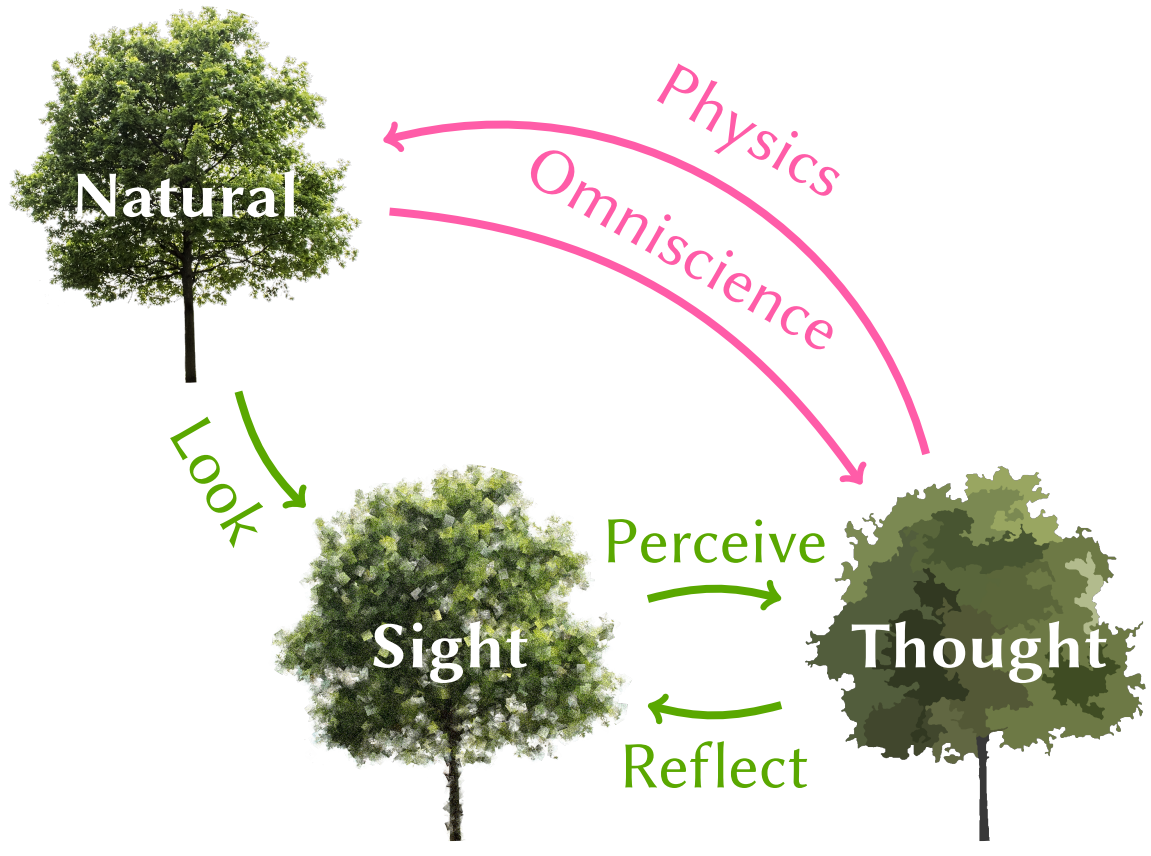
Thought
Reflect


Natural
Physics
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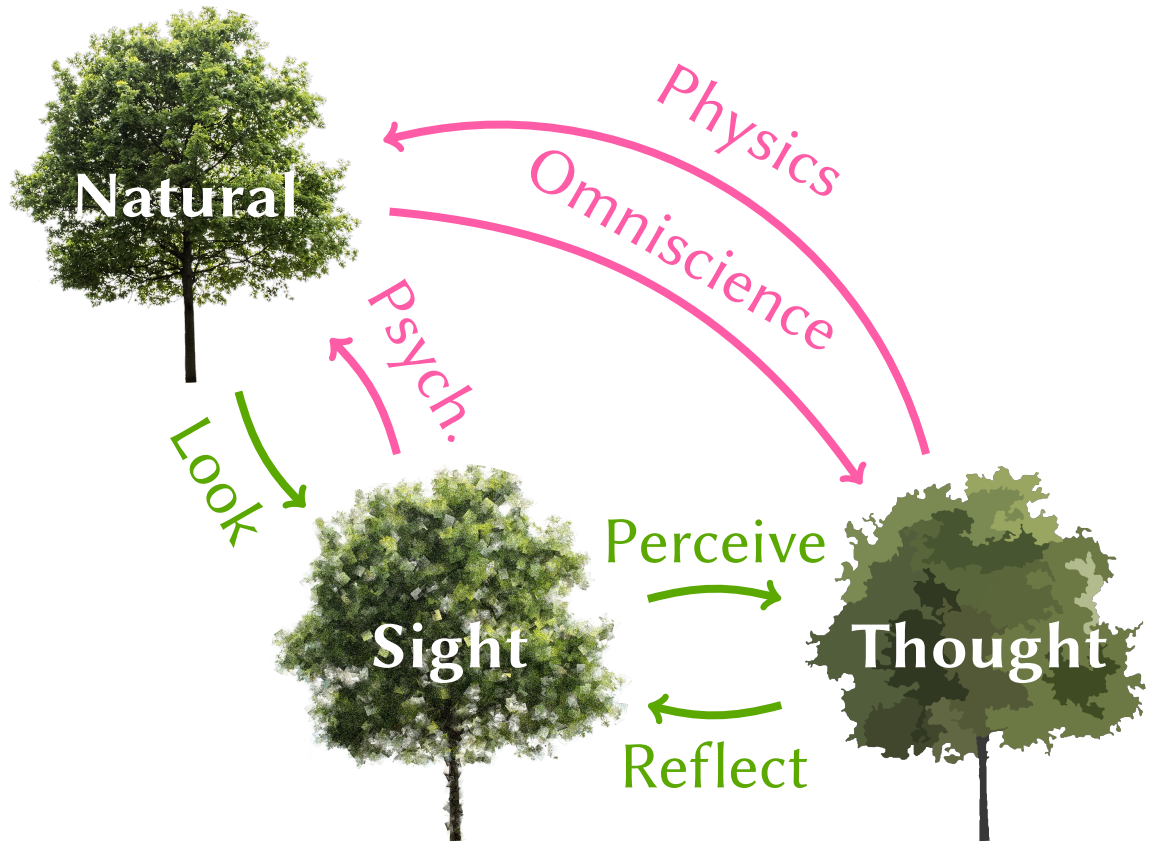
Natural
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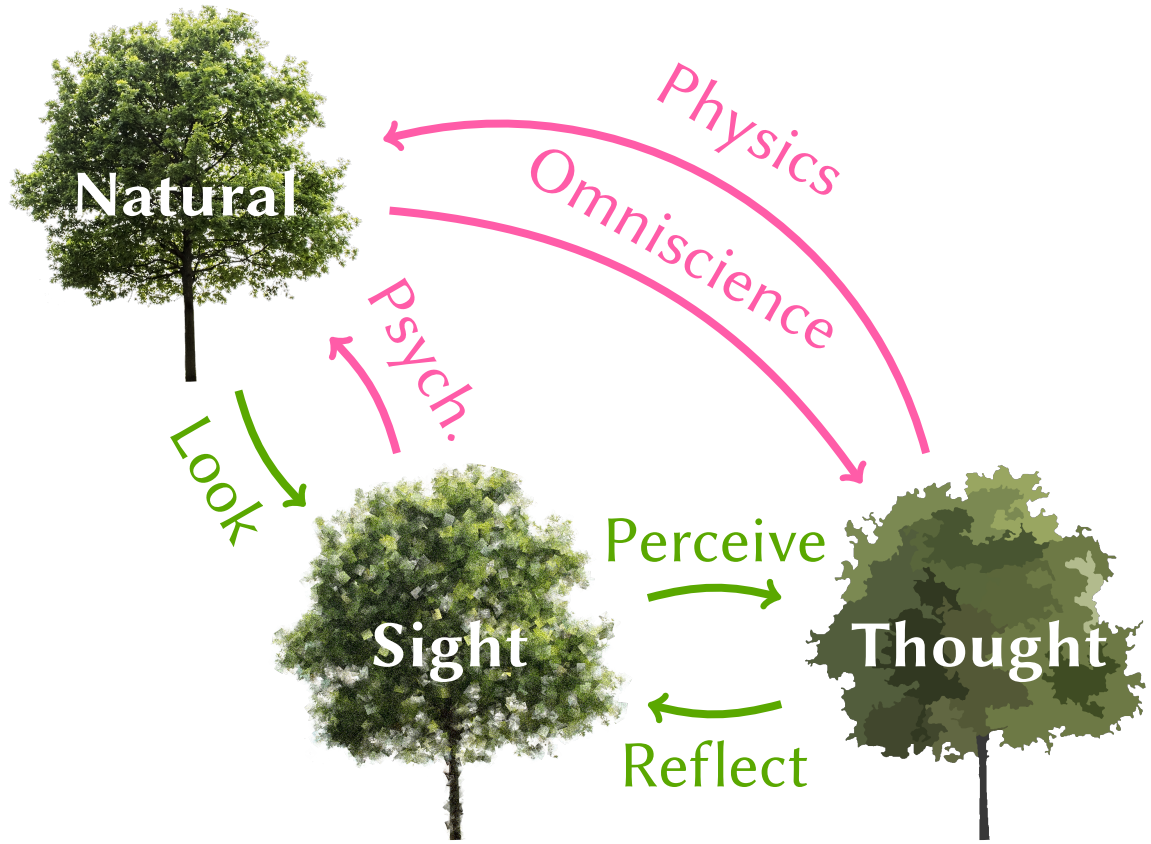
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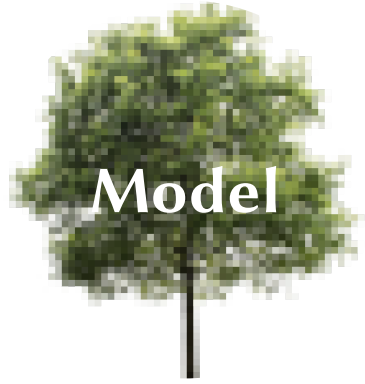
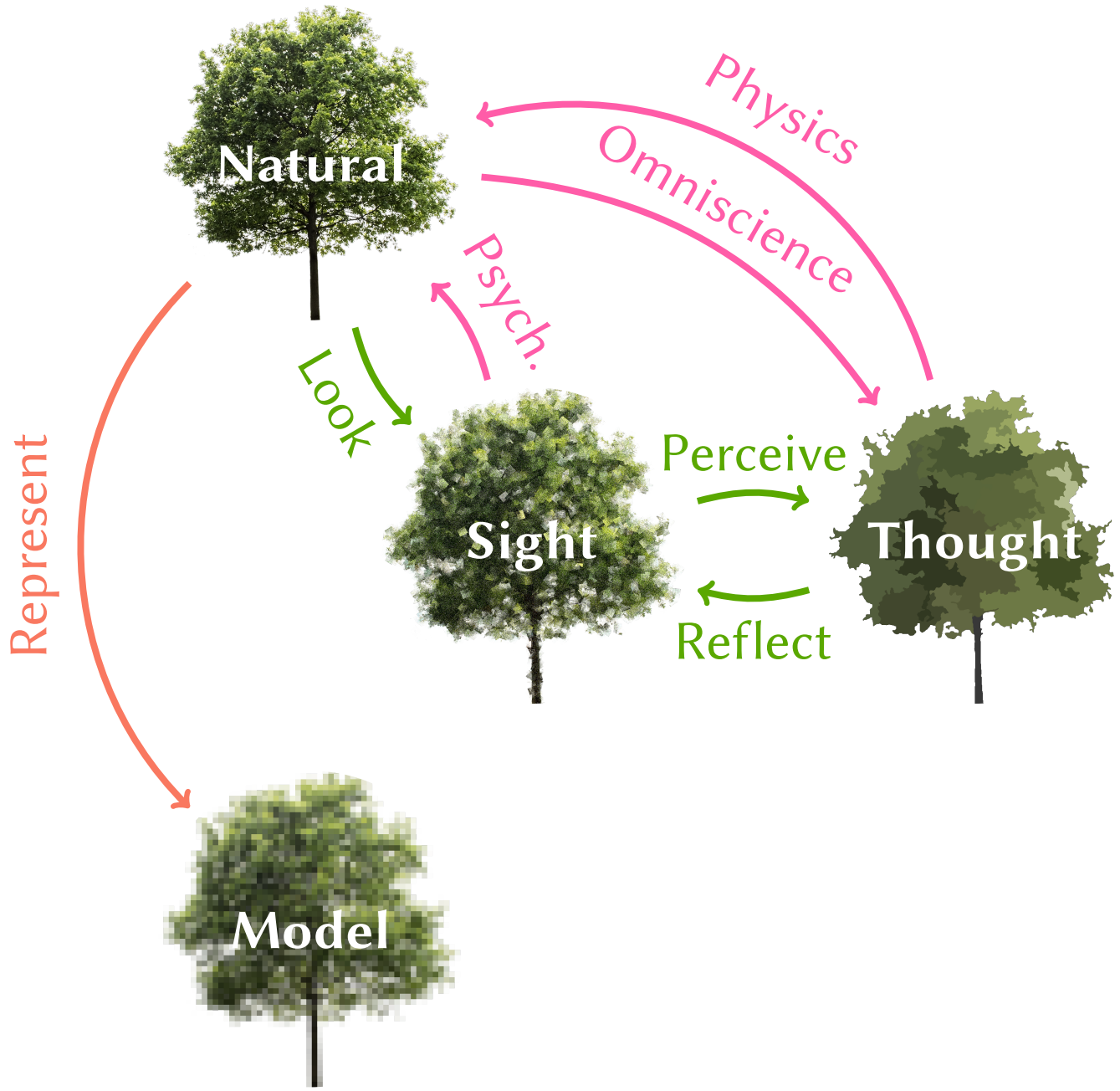

Model


Natural
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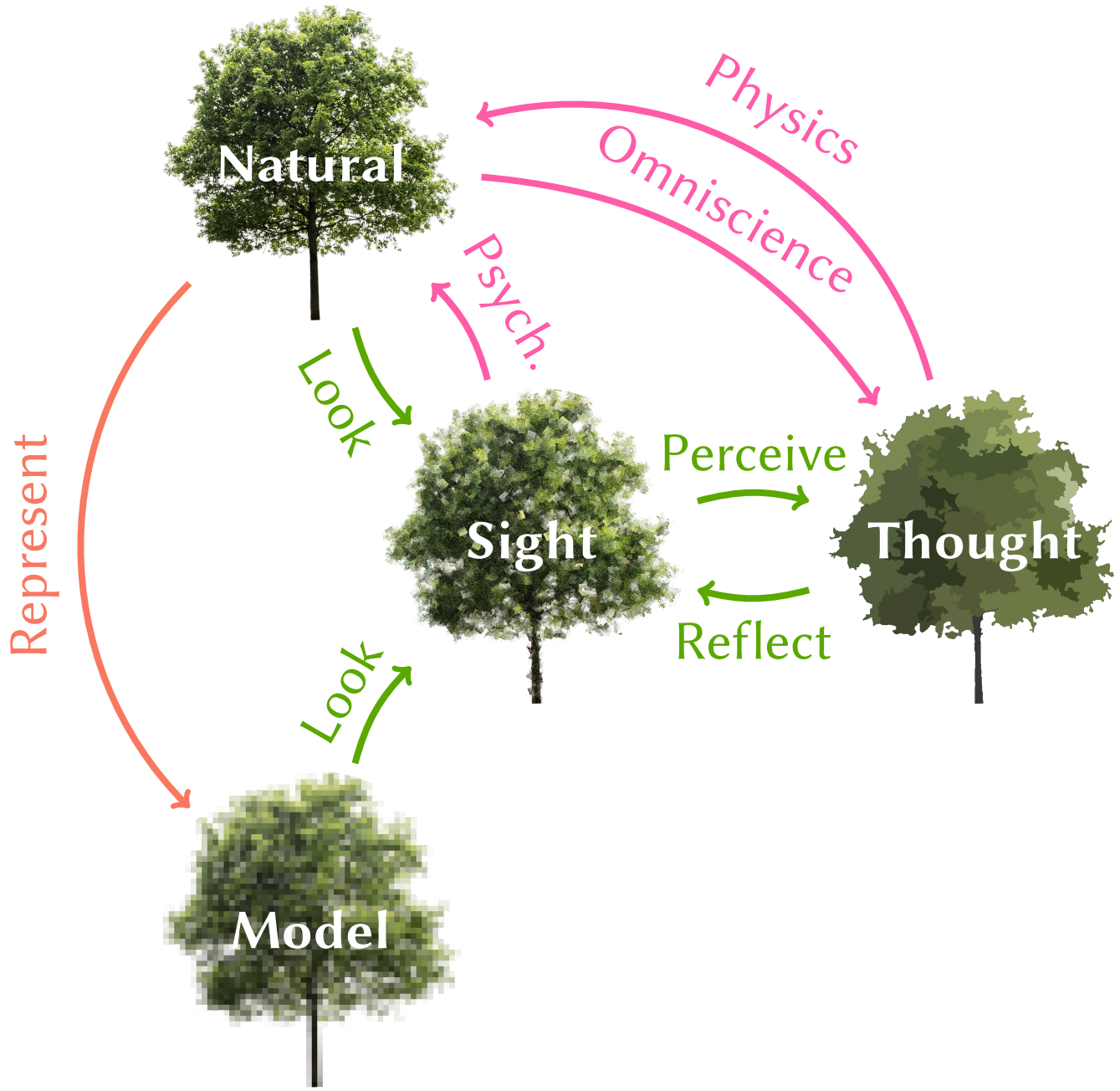
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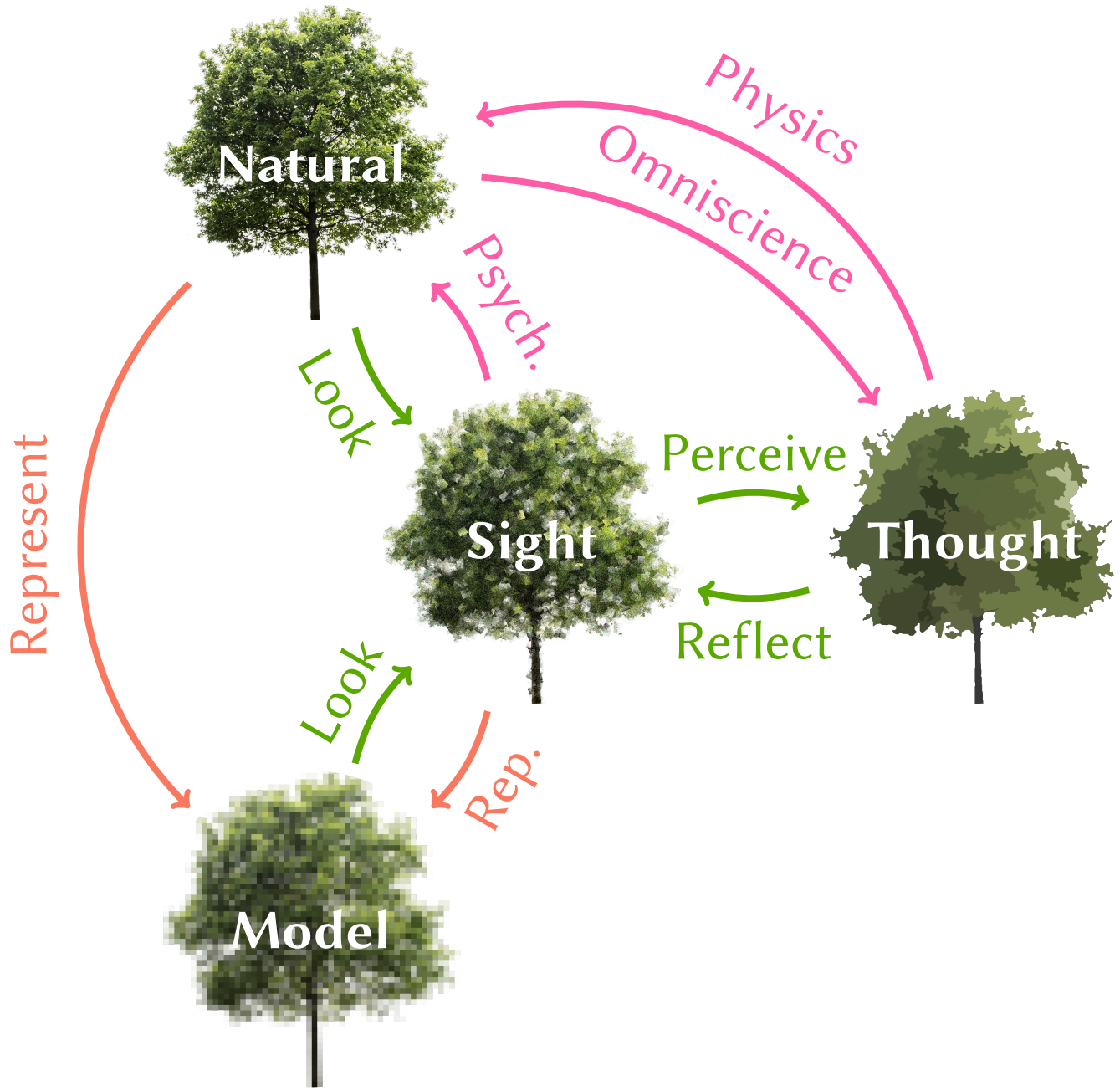
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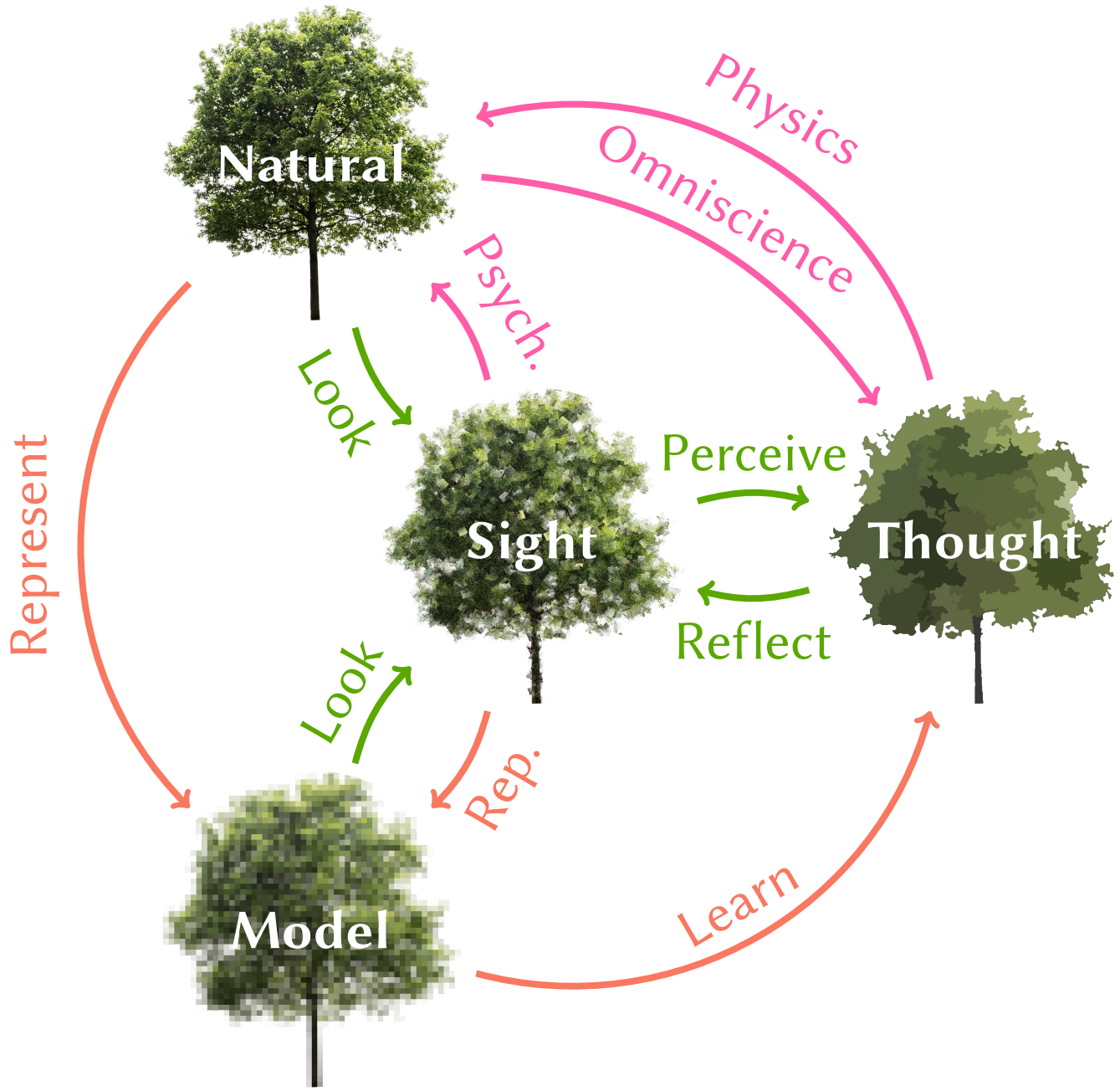
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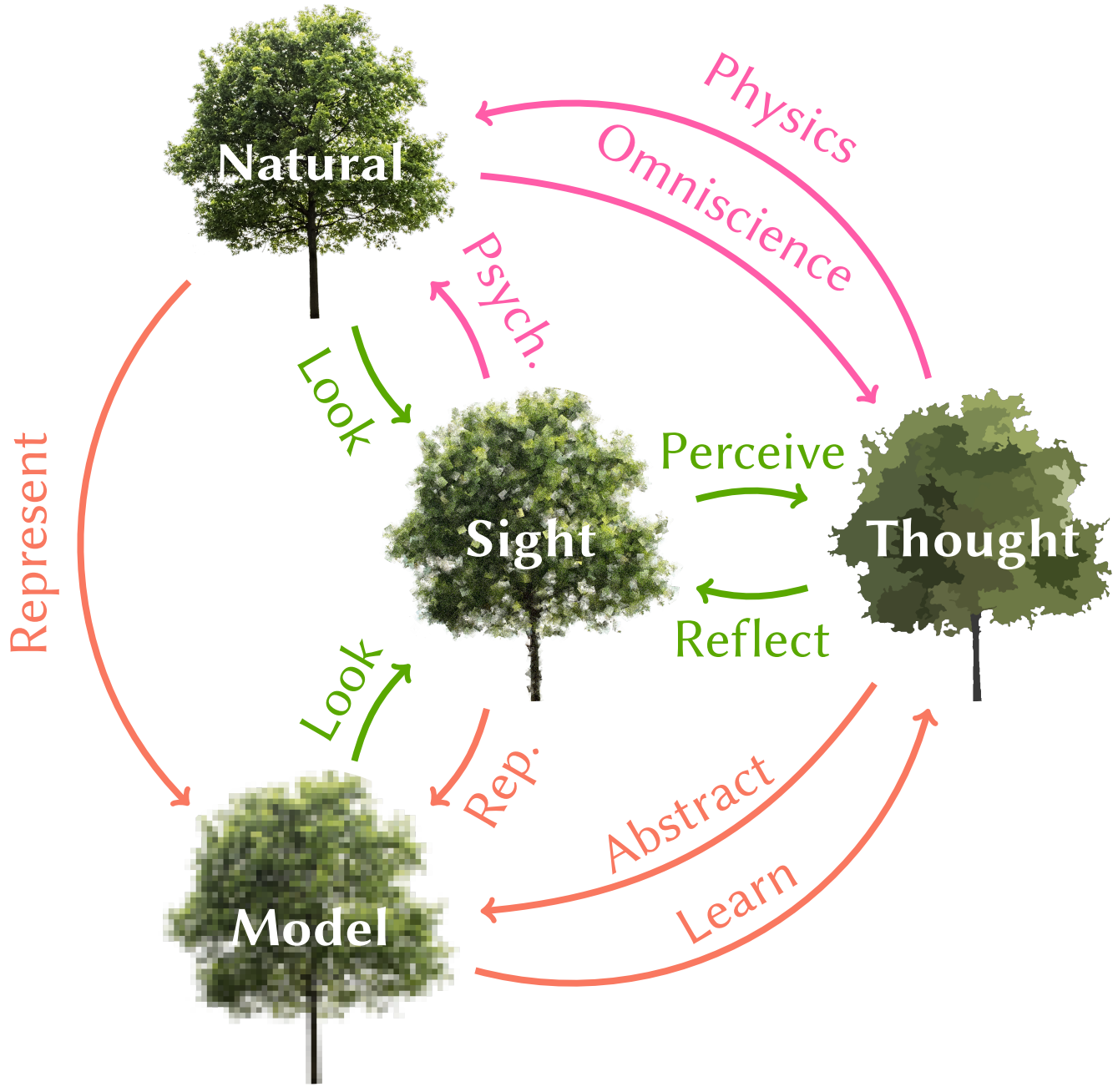
Model
Learn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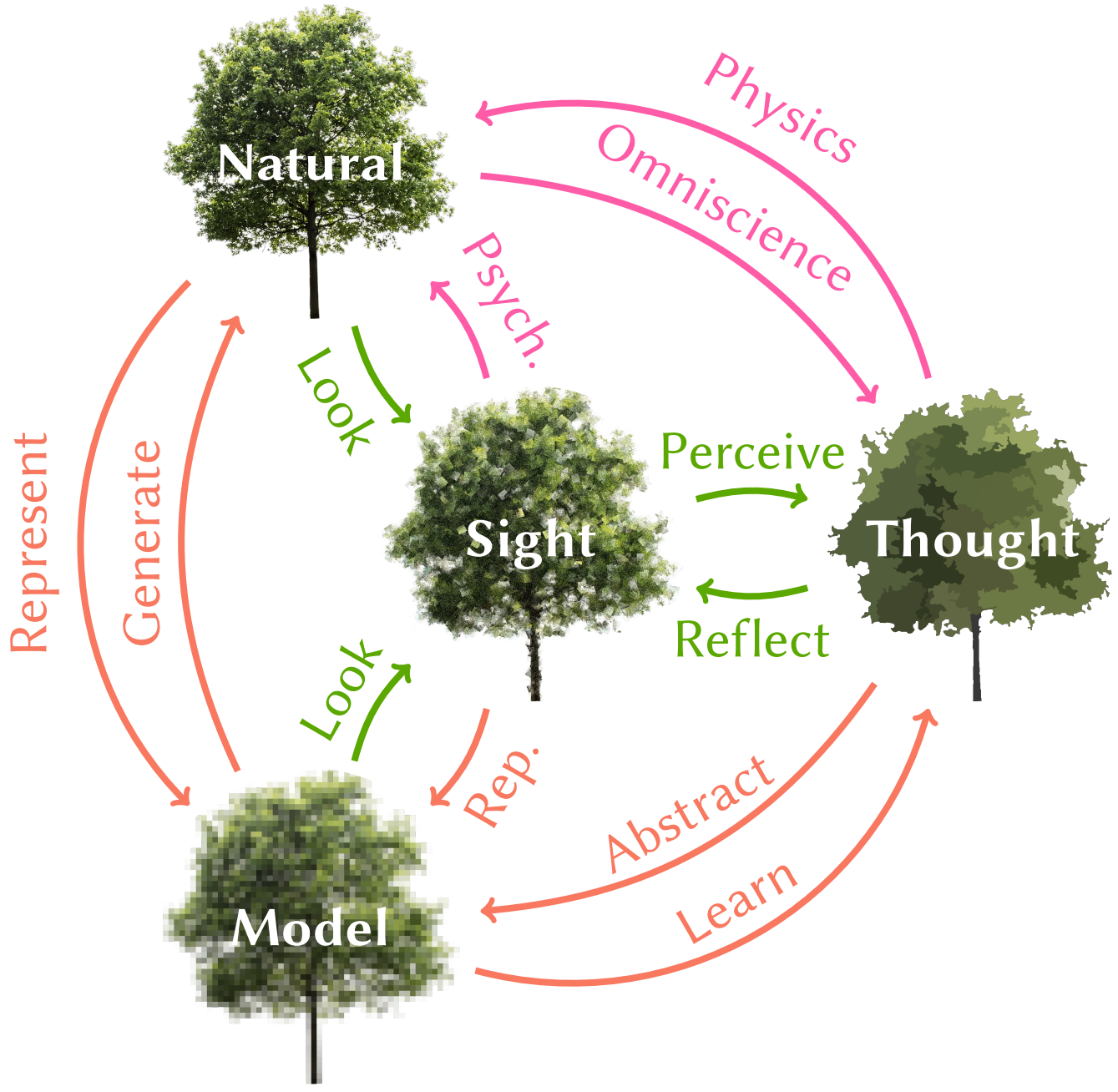
Abstract
Learn
Model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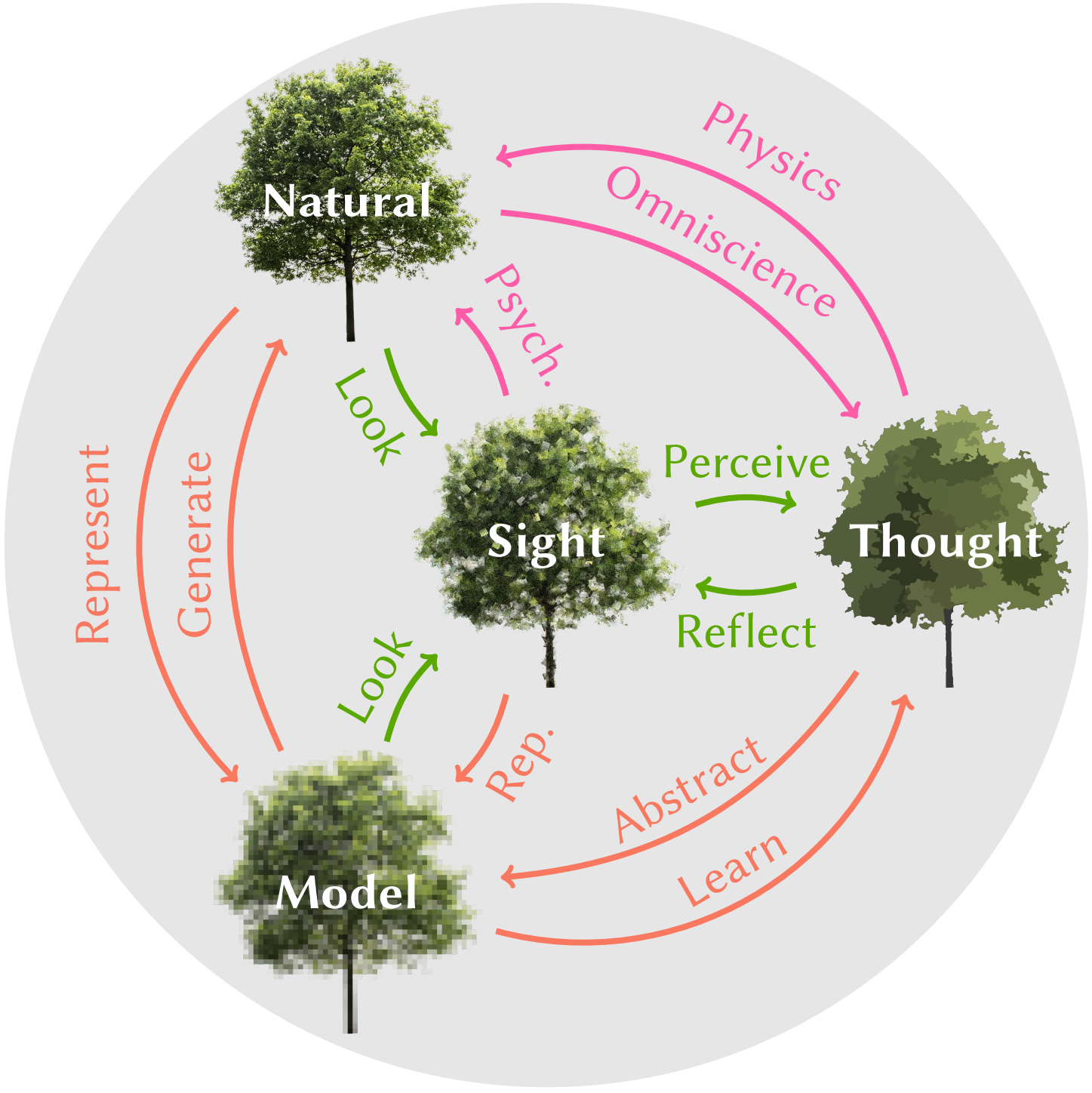

We cannot directly perceive the true nature of the world, but we can form models to indirectly perceive nature. A model must represent nature, while still being something we can readily look at and use to guide thought. **What are good models of how nature looks to us?**

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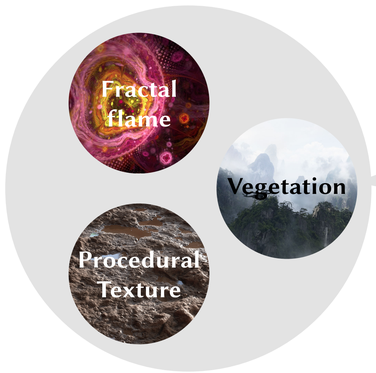
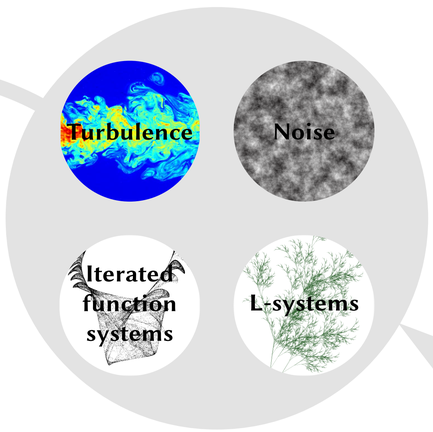
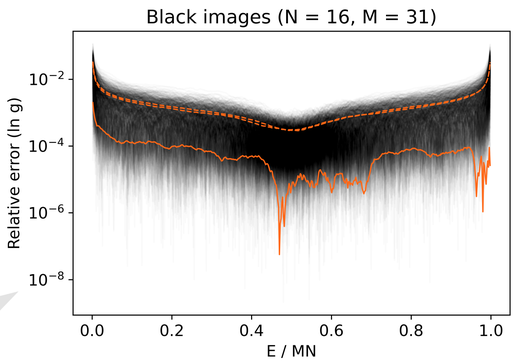


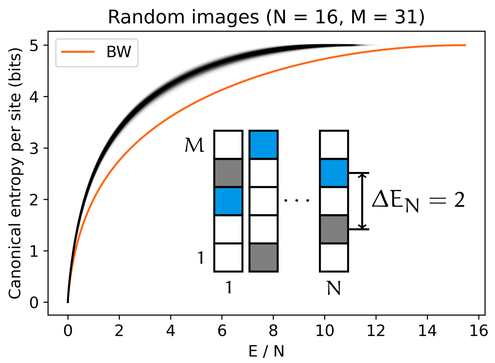
These methods are **widely used** to create graphics.

The electric sheep "fractal flame" screen saver is based on iterated function systems. Noise and turbulence are combined to procedurally generate textures for 3D models. L-systems are a component of *SpeedTree*, which is the software used to create vegetation for movies like *Avatar*.

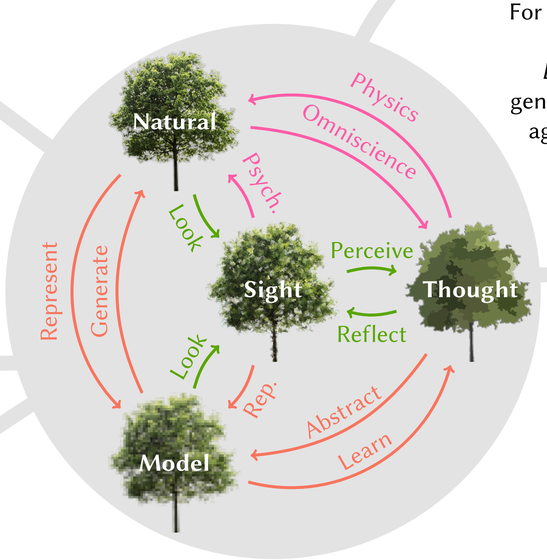


Visual complexity arises in many ways. Computational models of these phenomena are the bricks that build up the structure of an image.





For a notion of lost information in an image, we may perform simulations of **images as discrete-level systems**, where the energy is the sum of the differences in pixel values. The *Wang-Landau* algorithm was implemented for images, and confirmed to have the expected convergence properties on black or white (BW) images (*left*). Simulations for 1024 random grayscale images (*right*) reveal how entropy scales with how different the pixel values are (average energy).



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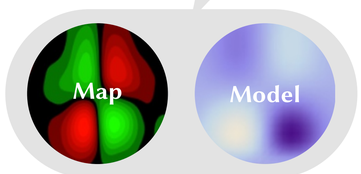
Statistical Physics and Information Theory

$$S = -\sum_{x\in\mathfrak{X}} p(x) \ln p(x) = \langle I \rangle_X$$

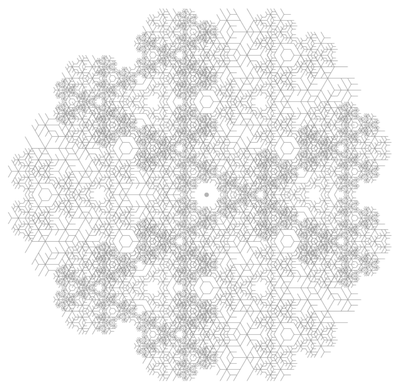
$$D_{KL}(p \parallel q) = \sum_{x\in\mathfrak{X}} p(x) \ln \frac{p(x)}{q(x)}$$

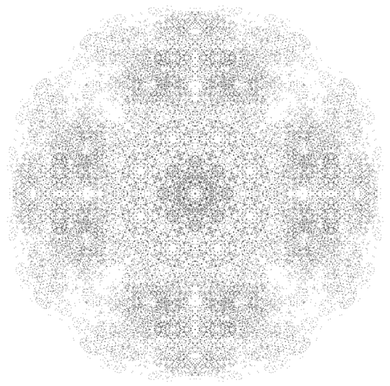
$$Z = \sum_{x\in\mathfrak{X}} e^{-\beta E(x)}$$



Receptive fields of *simple cells* in area V1 are modeled by space-time derivatives, and are related to smoothed derivatives of the light field entering the eye.

?





Visual complexity is challenging to express. Here we have shown just three perspectives: those of computation, psychophysics, and of statistical physics. Many more remain to be explored. The complexity that we see is deeply connected to the complexity and variety of physical phenomena in our world.