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Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Hestia

SUSTAINABLE PLACES

A Behaviour Digital Twin for Residential Demand Response

Modelling intention and motivation to improve the prediction of the likelihood of reaction to behavioural triggers

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Residential Demand Response

Motivation and Definition

- Going forward European “consumers should be able to benefit from directly participating in the [energy] market, in particular by adjusting their consumption according to market signals” [1]
- This can be supported by suitable residential demand response schemes, which aim at “reducing or shifting [...] electricity usage during peak periods in response to time-based rates or other forms of financial incentives” [2]

[1]Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity

[2]https://www.energy.gov/oe/demand-response

Residential Demand Response

Key challenges

- Financial incentives for the individual household are limited and thus far have produced limited outcomes [3,4]
- Therefore, “market participants engaged in aggregation are likely to play an important role as intermediaries between customer groups and the market” [1]

[1]Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity.
[3] Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda.
[4]He, H. A., Greenberg, S., & Huang, E. M. (2010). One Size Does Not Fit All: Applying the Transtheoretical Model to Energy Feedback Technology Design.

Residential Demand Response

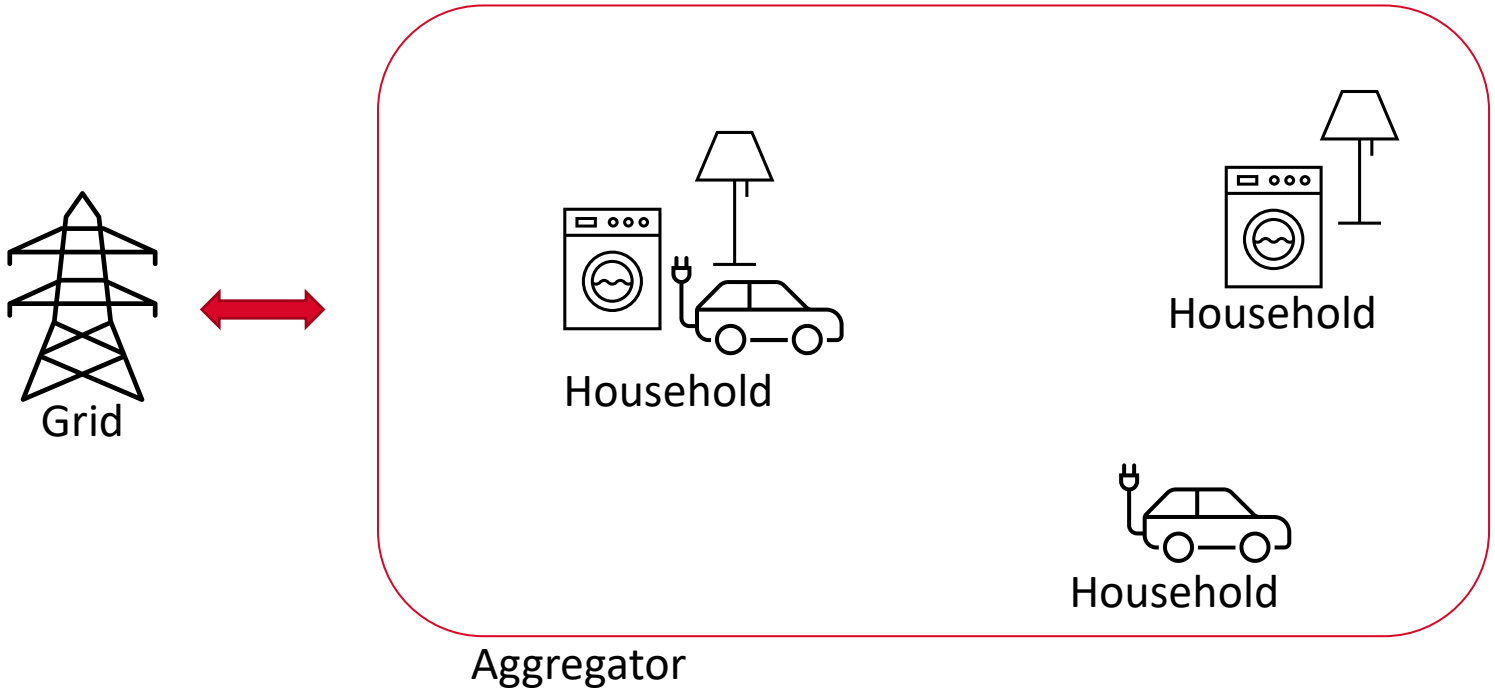
Key challenges

- However, these “independent aggregators” [1] will depend on their customers’ willingness to adapt their behaviour when required by the grid
- The flexibility available to the market therefore not only depends on available flexibility assets but crucially also on the motivation and intentions of participating individuals

[1]Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity

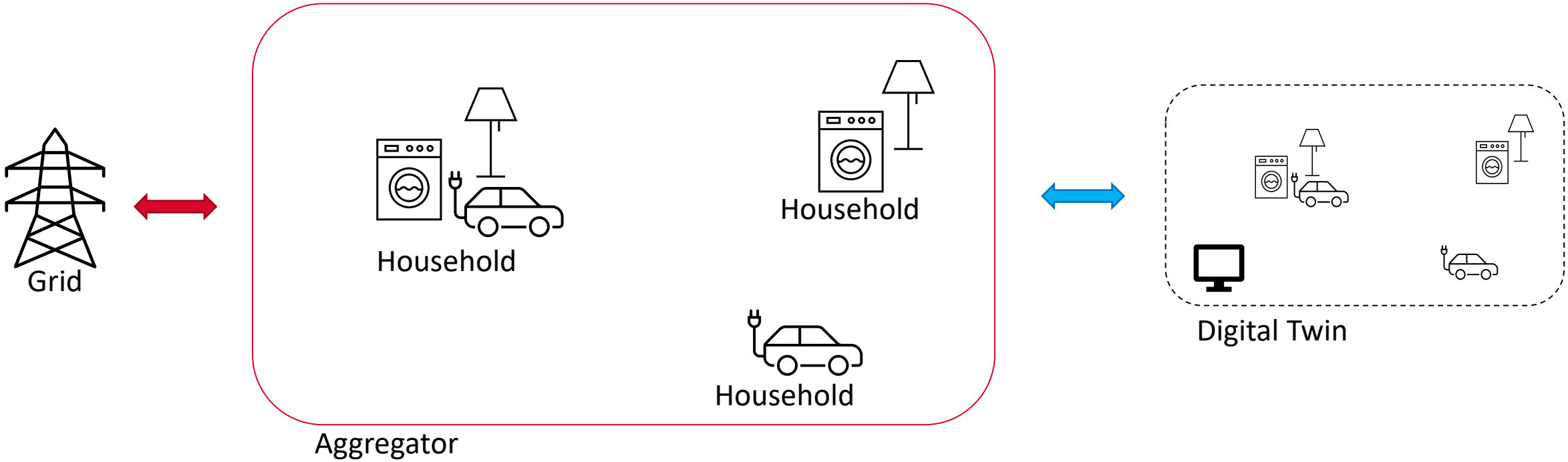
Behaviour Digital Twin

Aggregators sell household flexibility to the grid



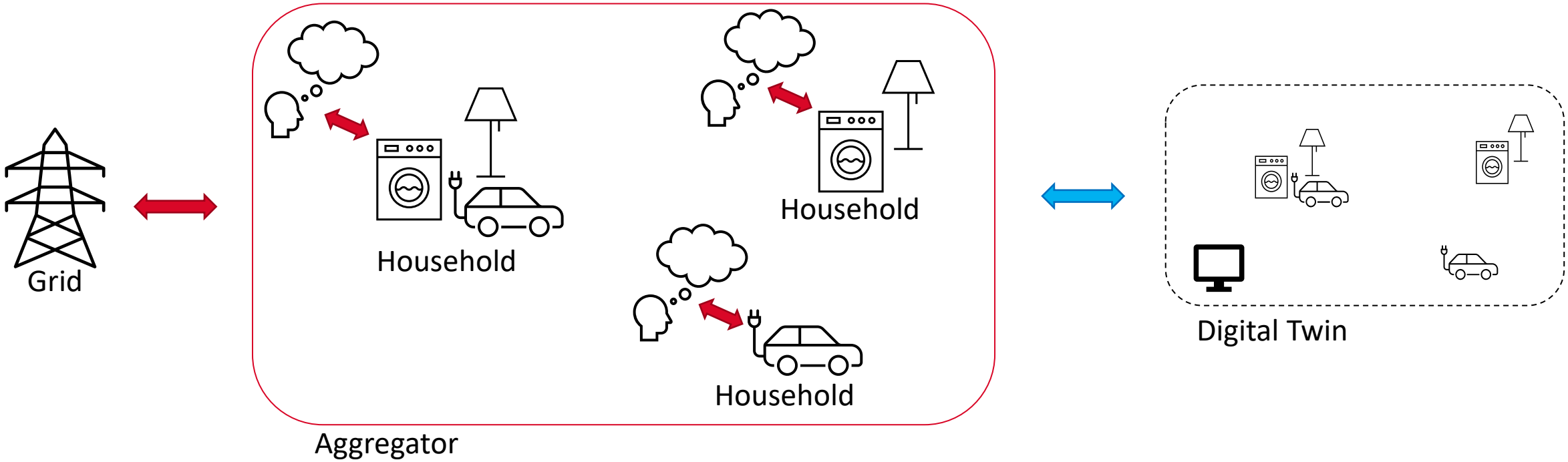
Behaviour Digital Twin

They use digital twins to mirror available energy assets



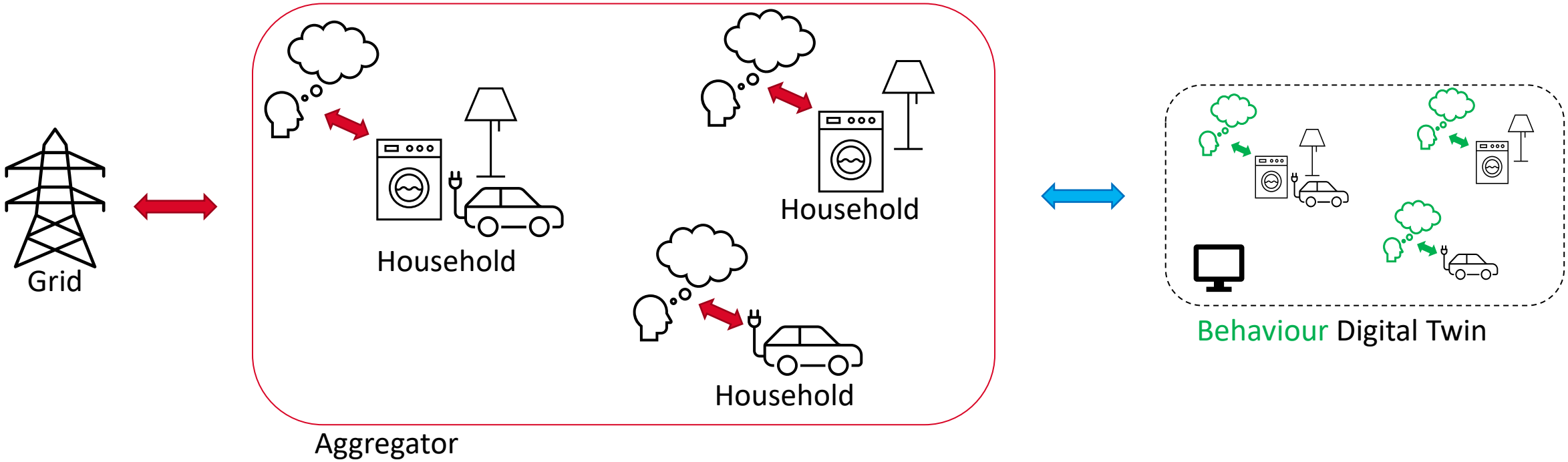
Behaviour Digital Twin

Control of household appliances requires end-user interaction



Behaviour Digital Twin

A residential digital twin should also consider end-user behaviour



Behaviour Digital Twin

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Intention and motivation

- The likelihood of an individual to respond to a request depends on their intention and motivation [5]
- Psychological behaviour models have been developed to assess such variables through empirically validated inventories [6,7]

[5]Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention and behaviour: An introduction to theory and research.*
[6]Ajzen, I. (1985). Ajzen, I. (1985). From Intentions to Actions: A Theory of Planned Behavior.
[7]Ryan, R. M., & Deci, E. L. (2000). Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being.

Theory of Planned Behaviour

Assessing short-term intention

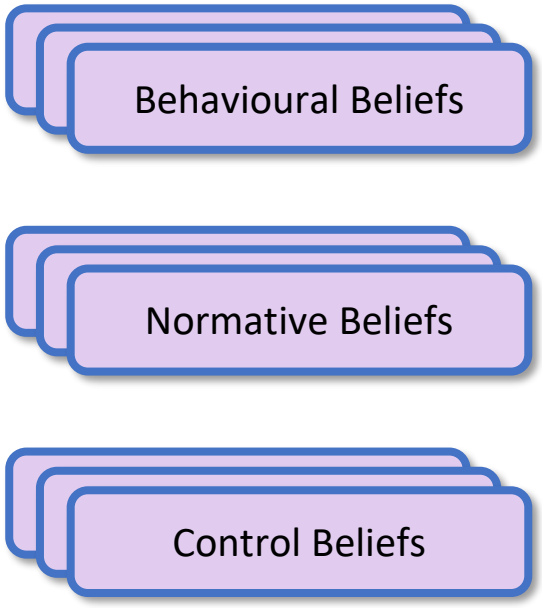
- Intention is the "subjective probability of a person to perform the behaviour in question in respect to a given object"[5]
- To measure the behavioural intention the TPB proposes a framework for assessing a person's beliefs through structured questionnaires

[5]Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention and behaviour: An introduction to theory and research.*

Theory of Planned Behaviour

Example questions to assess energy flexibility beliefs

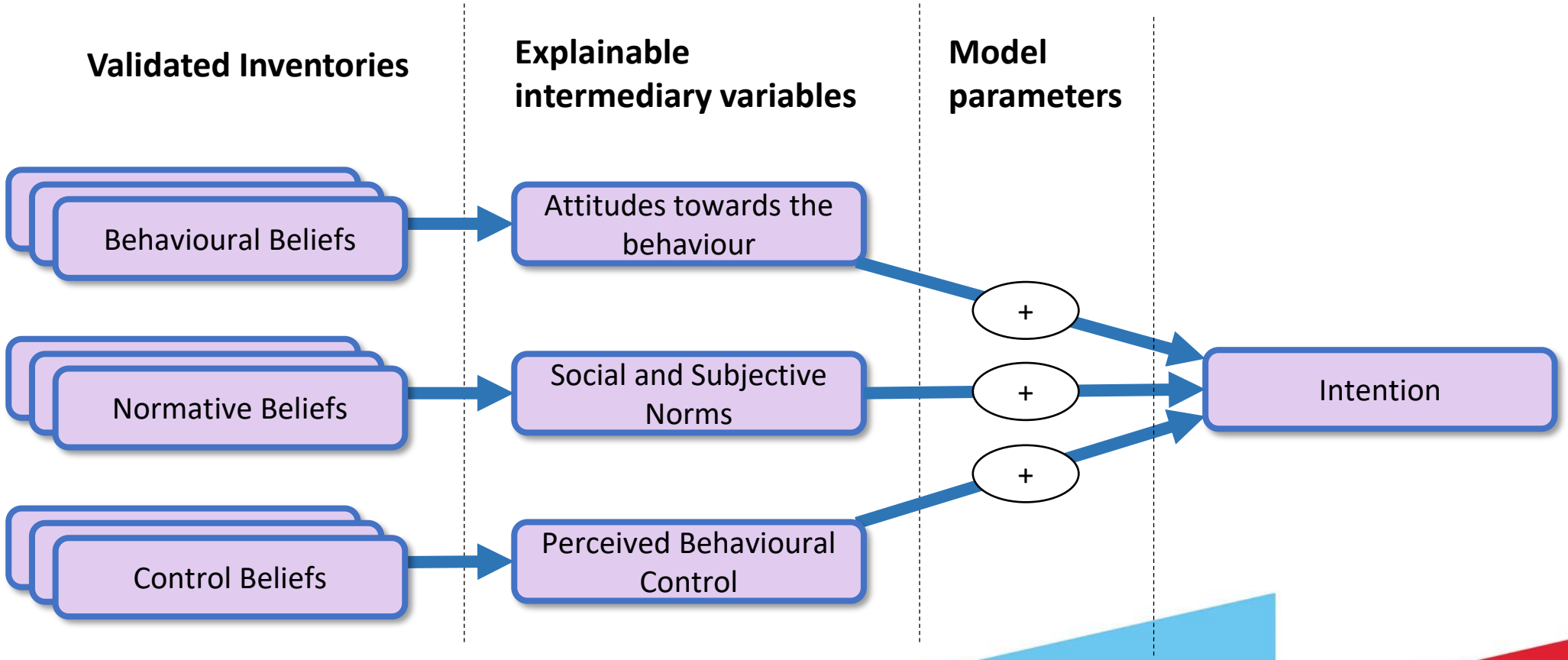
Validated Inventories



- It is important to me to adjust my behaviour according to energy availability to support a more environmentally friendly life-style.
- Most of my friends would adjust their behaviour according to the availability of energy.
- It sounds easy to use energy at the right time.

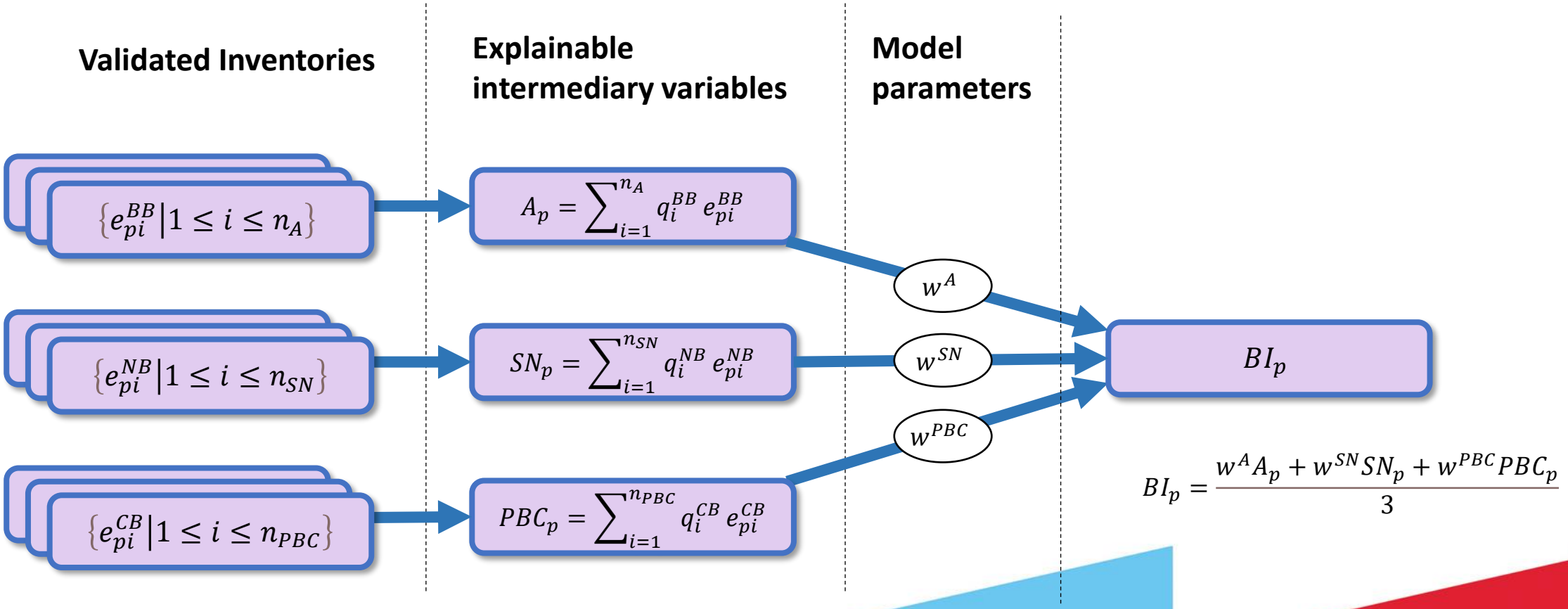
Theory of Planned Behaviour

A psychological model to calculate behavioural intentions



Theory of Planned Behaviour

Operationalisation of the model



$$BI_p = \frac{w^A A_p + w^{SN} SN_p + w^{PBC} PBC_p}{3}$$

Self-Determination Theory

Assessing long-term motivation

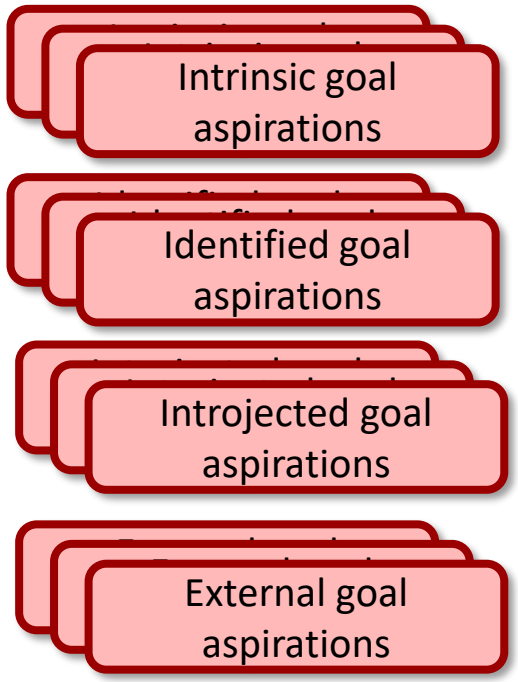
- Motivation is seen as a more general tendency towards a specific subject area[8]
- To measure the motivation the SDT proposes a framework for determining a person's relative autonomy by assessing their goal aspirations through structured questionnaires

[8]Blanke, J., Billieux, J., & Vögele, C. (2022). Healthy and sustainable food shopping – A Survey of Intentions and Motivations.

Self-Determination Theory

Example questions to assess energy flexibility goal aspirations

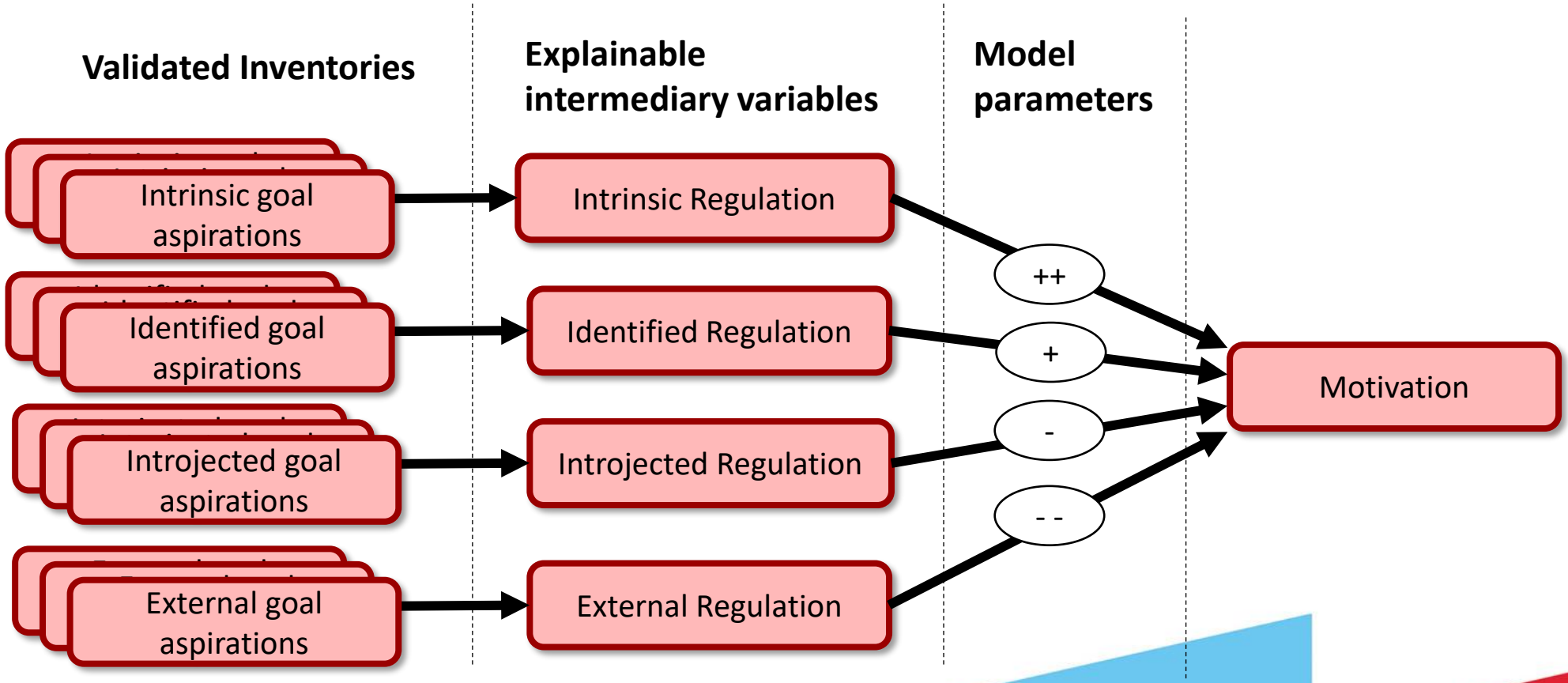
Validated Inventories



- I simply enjoy supporting the environment, even if that means that I have to adapt my behaviour.
- Adjusting my behaviour in a way that it matches energy availability is good for the environment.
- I would feel bad about myself if I didn't adjust my behaviour depending on if energy is available or not.
- It helps my image in the neighbourhood and community to show energy flexibility.

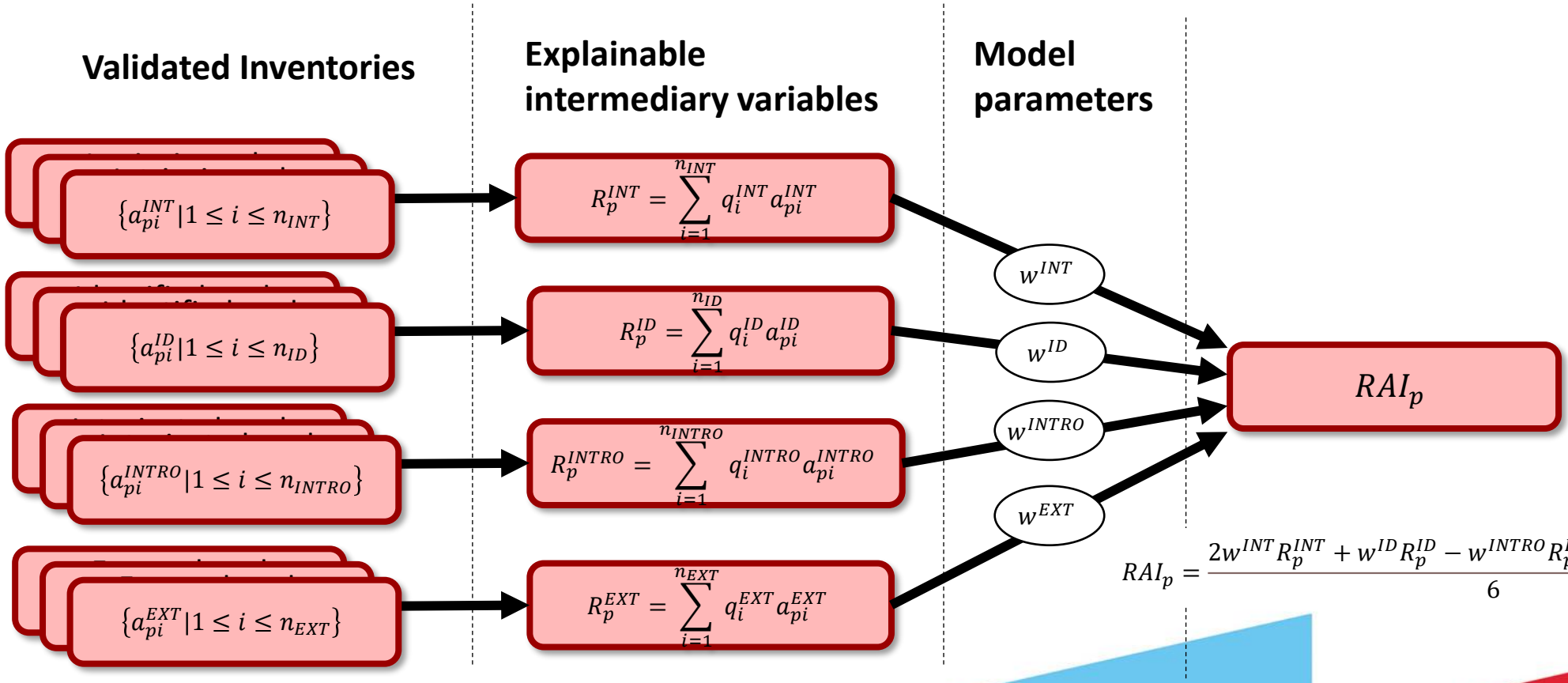
Self-Determination Theory

A psychological model to calculate motivation



Self-Determination Theory

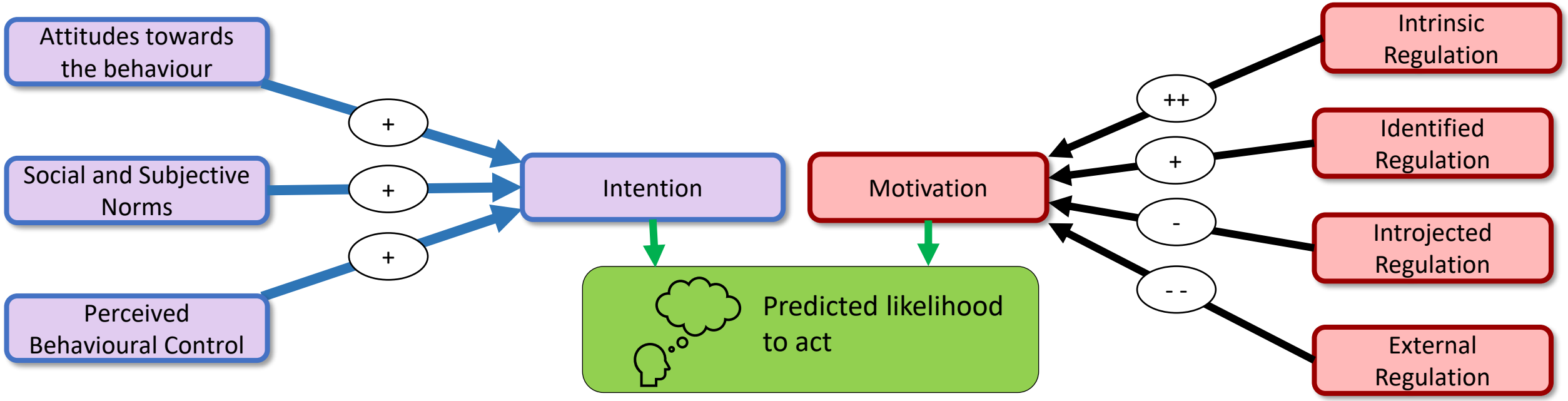
Operationalisation of the model



$$RAI_p = \frac{2w^{INT}R_p^{INT} + w^{ID}R_p^{ID} - w^{INTRO}R_p^{INTRO} - 2w^{EXT}R_p^{EXT}}{6}$$

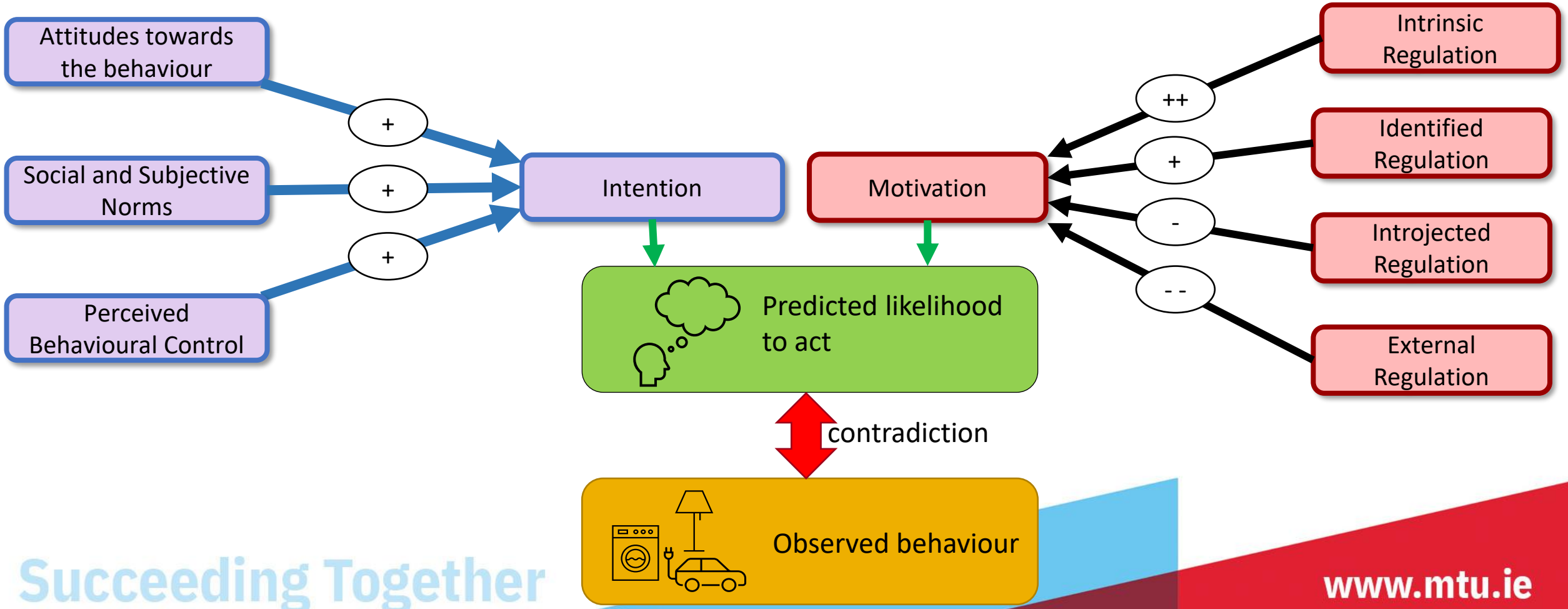
Predicting the Likelihood to act

Combining intention and motivation



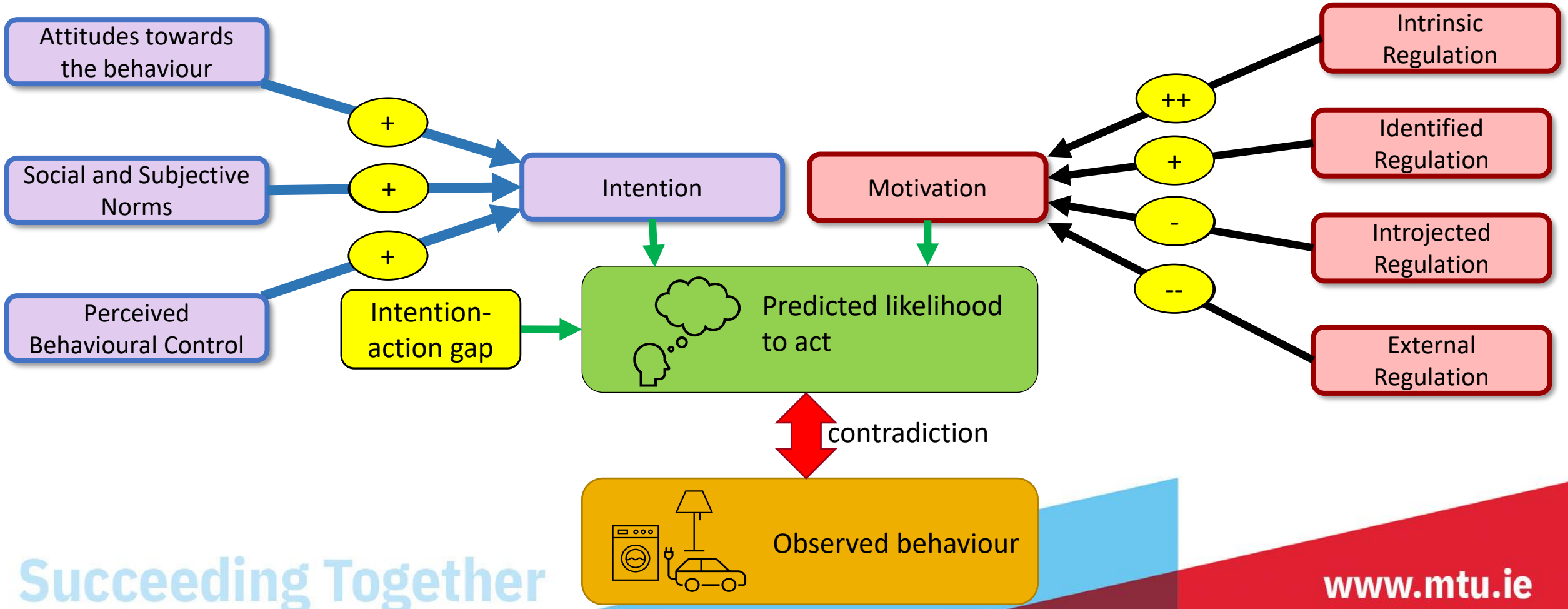
Predicting the Likelihood to act

Observing the contradiction with actual behaviour



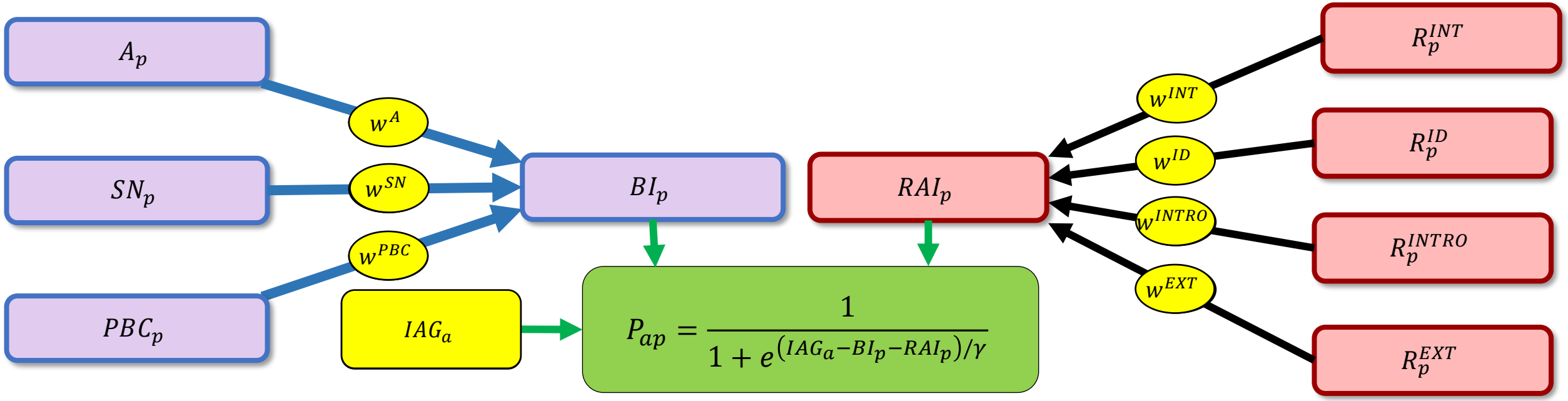
Predicting the Likelihood to act

Continuous minimisation of contradiction by adapting weights



Predicting the Likelihood to act

Every individual's likelihood to act can be calculated



Summary

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Behaviour Digital Twin

- Model predictive control is challenging to implement in aggregated residential settings
- Predicting the probability that a person will react to a trigger message combined with the available flexibility is vital for deciding whom to target and when in a dynamic residential demand response scenario
- Assessing intention and motivation and continuously adapting to actual observed behaviour is a promising approach
- Psychological inventories provide a validated methodology for measuring key variables and can be operationalised into a Behaviour Digital Twin model

Thank you for your attention

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