

**Lecture 4:
A Theory/Model Approach for
Empirical Design Disciplines**

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Introduction

- **Natural Sciences have a rigorous experimental basis**
 - ↪ Theories have to be testable
 - ↪ Testing is done in the physical world
 - ↪ Physical world provides hard constraints on theories
- **Behavioral Sciences also a rigorous experimental basis**
 - ↪ Testing have to be testable
 - ↪ Testing is done in the behavioral world
 - ↪ Behavioral world provides probabilistic constraints
- **Artificial Sciences have a woefully inadequate experimental basis**
 - ↪ Theories have to be testable
 - ↪ Testing is done in a combination of intellectual, behavioral, technological and physical worlds
 - ↪ Physical world provides hard constraints on theories
 - ↪ Technological world provides selectable constraints
 - ↪ Behavioral world provides probabilistic constraints
 - ↪ Intellectual context provides malleable constraints

Interesting Differences

→ Natural sciences

- ↳ Understand natural phenomena
- ↳ Theoretical basis for prediction
- ↳ Basis for invention/engineering

→ Behavioral sciences

- ↳ Understand human and societal phenomena
- ↳ Theoretical basis for predictions and interventions
 - Basis for prediction
 - Basis for intervening and changing the world
 - ✓ SE also has this property
- ↳ Basis for therapy, education, policy, motivation, etc

Motivation

→ Immaturity of empirical software engineering (ESE)

- ↳ Lack of understanding of empirical problems
- ↳ Lack of understanding of empirical issues
- ↳ Lack of understanding of empirical possibilities
- ↳ Lack of understanding of empirical designs

→ Provide foundations for rigorous ESE

↳ Current state:

- Weak evaluations - problematic
- Rely too much on marketplace evaluation

↳ Desired state

- Clearly stated theories
- Rigorously evaluated
- With appropriate and well-designed empirical studies
 - ✓ Designs appropriate for the entire range of ESE
 - ✓ As much facility with empirical study design as with software design

A Metaphor

→ Osterweil, *Software Processes are Software Too*, ICSE 9 (1987)

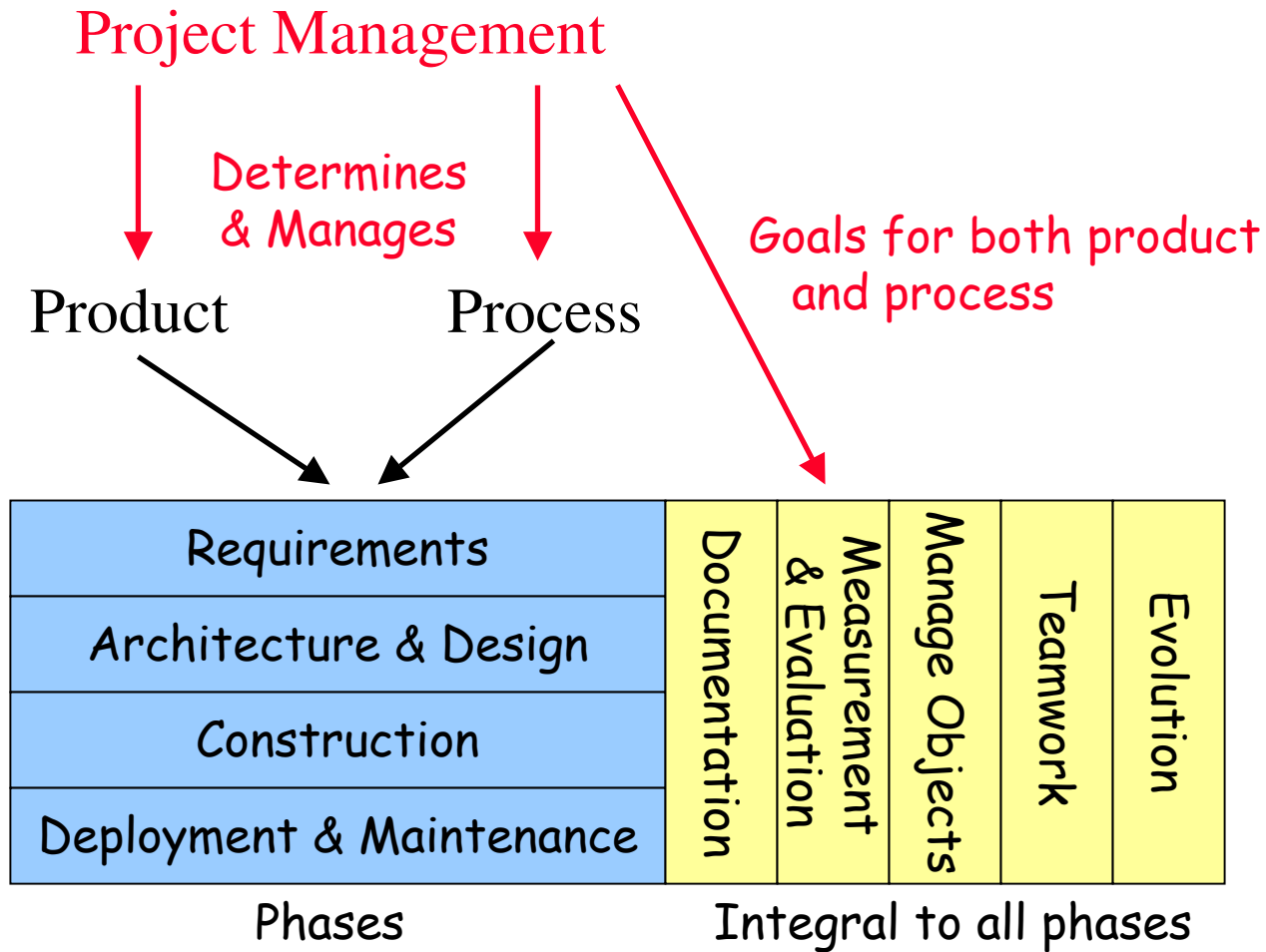
- ↳ Software process systems are analogous to software product systems
- ↳ They go through the same life cycle
- ↳ They have the same integral aspects across the life cycle

→ What is important?

- ↳ Life cycle processes and integral aspects are the same
 - Think of them as components with the same interfaces
 - But different implementations
- ↳ Details differ because of different domains
 - Implementation details depend on the domain
 - Ie, whether process or program

→ Claim: present an analogous foundation for empirical studies in software engineering

SE Life-Cycle



Motivation

- Treat empirical studies as a design discipline analogous to software
 - ↳ Taking Osterweil's approach even further
- Science requires rigorous empirical basis
- Want to move ESE from
 - ↳ *Alchemy of design to Science of design*
 - ↳ *Craft to Engineering*

Overview

→ Introduce theories and models for

- ↳ Basic theory-model theory and model (TM)
- ↳ Applied to itself - meta model theory and model (MTM)
- ↳ Basic empirical theory (E)
- ↳ Apply E to TM, MTM and to itself as well (yielding EE)

→ To evaluate, instantiate theories and models for

- ↳ Software systems TS, MTS
 - Will provide examples to illustrate - sketch the rest
- ↳ Project management TD, MTD
- ↳ Empirical instruments TI, MTI
- ↳ Empirical designs TE, MTE

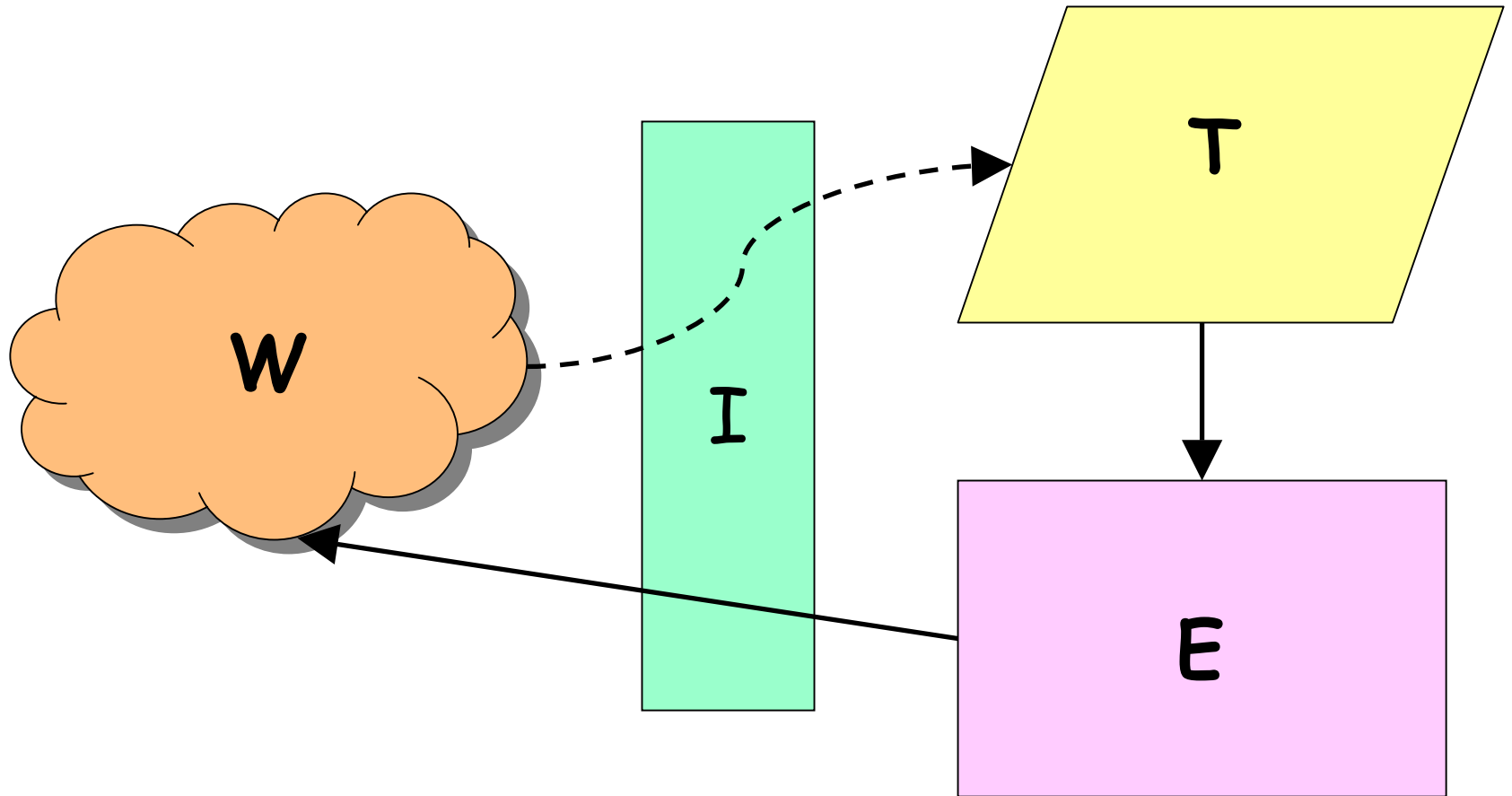
→ Value of my approach

- ↳ Simple approach that captures basics
- ↳ Widely applicable - used the approach on itself
- ↳ E and EE lay out a space and a provides structure for ESE

Comment

- The theory-model approach is a natural one for design intensive activities
- The discussion here will present TM, MTM, E and EE in very abstract and simple terms
 - ↳ This will enable us to focus on the critical issues with out getting bogged down in the wealth of details and the richness of software engineering and empirical studies

Basic Science



Basic Science

→ Basic iterative process

- ↪ Observation and abstraction → create theory (T)
- ↪ Test theory against reality (W) with experiments (E)
- ↪ Reconcile theory with reality

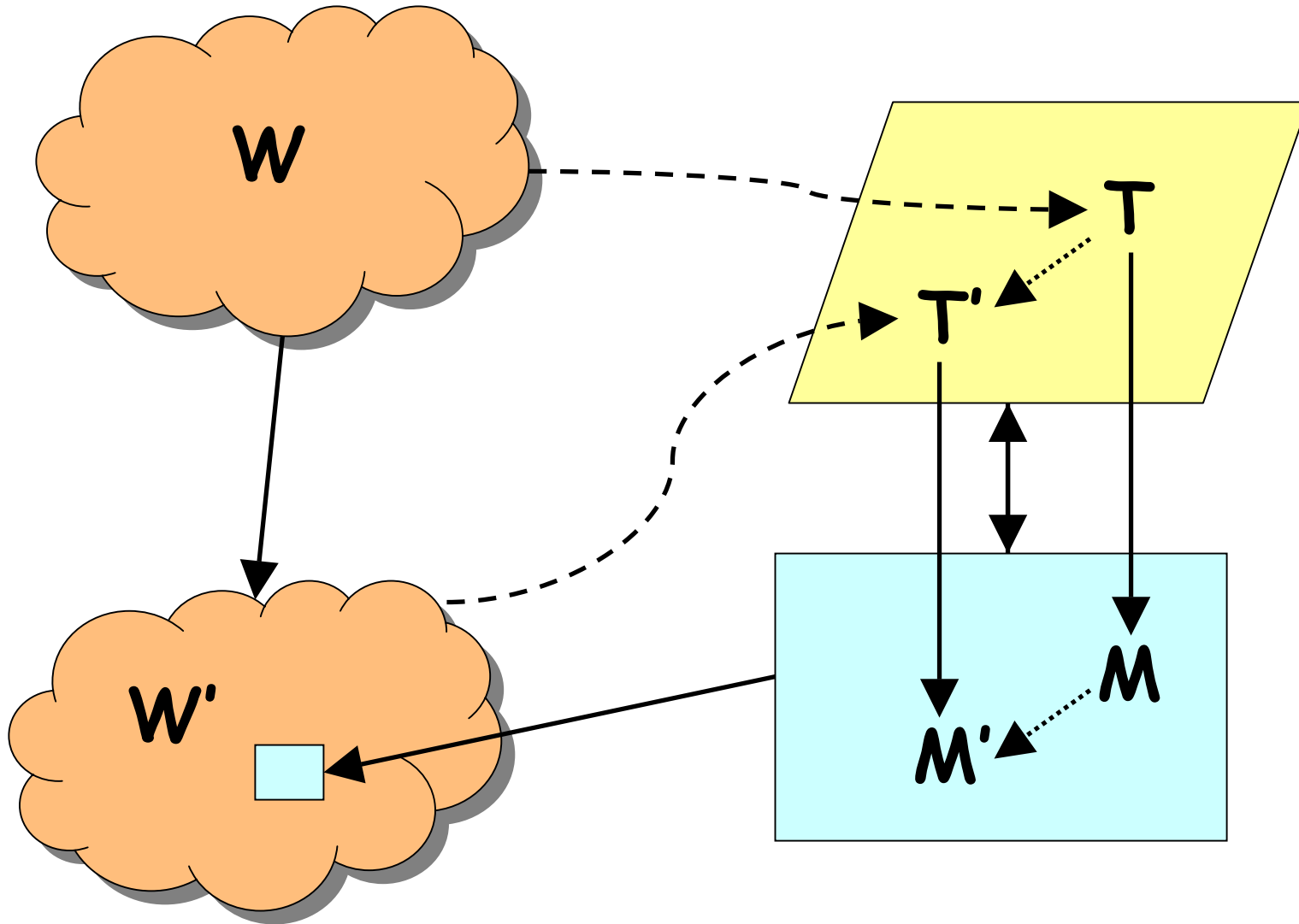
→ Importance of instruments (I) [Gooding et al]

- ↪ The lens through which we observe the world
- ↪ Type of instruments
 - Natural sciences: physical creations
 - Behavioral sciences: intellectual creations
 - Humans are a common instrument in both
- ↪ To paraphrase Wittgenstein: **the limits of my instruments are the limits of my world** [Perry]
 - Enhance, limit, color our view of the world
- ↪ Important characteristics of our instruments
 - Active vs passive instruments
 - Invisibility (transparency) vs theory-laden
 - Reliability and standardization
 - ✓ Replication and credibility

Why TM Theory?

- As with Behavioral Sciences, SE interested in changing the world
- Models reify theory
 - ↳ Provide concrete realization of theory
- Models often used in empirical work
 - ↳ Need observable constructs
 - ↳ Need concrete treatments/manipulations/interventions
- Benefits
 - ↳ Small theory - applicable to all of SE and ESE
 - ↳ Yields a taxonomy of experiments
 - ↳ Applicable because of design nature of SE and ESE tasks

Basic Theory-Model Theory (TM)



Theory TM

- We observe and abstract some specific part of the world and create a theory
- From that theory we create a usable model to represent the theory
- We iteratively adjust both the theory and the model as our understanding of the theory and the model evolves
- When satisfied, we inject the model into the world
- Injecting the model into the world changes the world
- These and other changes in the world often lead to adjustments and extensions to the original theory
- This then leads to further changes in the model and world

Model TM

→ **W**

↳ The world - more specifically, the relevant part of the world

→ **T**

↳ The theory initiated by observation and abstraction

→ **M**

↳ A model that satisfies the theory

→ **W** → **T**

↳ Generate a theory: observe and abstract from the world (W) to create a theory (T)

→ **T** → **M**

↳ From theory (T) create a model (M) [T&M]

→ **T** → **T'**

↳ Frequently evolve the theory until satisfied

Model TM

→ $M \rightarrow M'$

↳ We frequently evolve the model until (often only temporarily) satisfied

→ $T \leftrightarrow M$

↳ We frequently adjust the model and the theory to each other - ie,

- Change the model to better satisfy the theory
- Change the theory to conform with the model

→ $M \rightarrow W'$

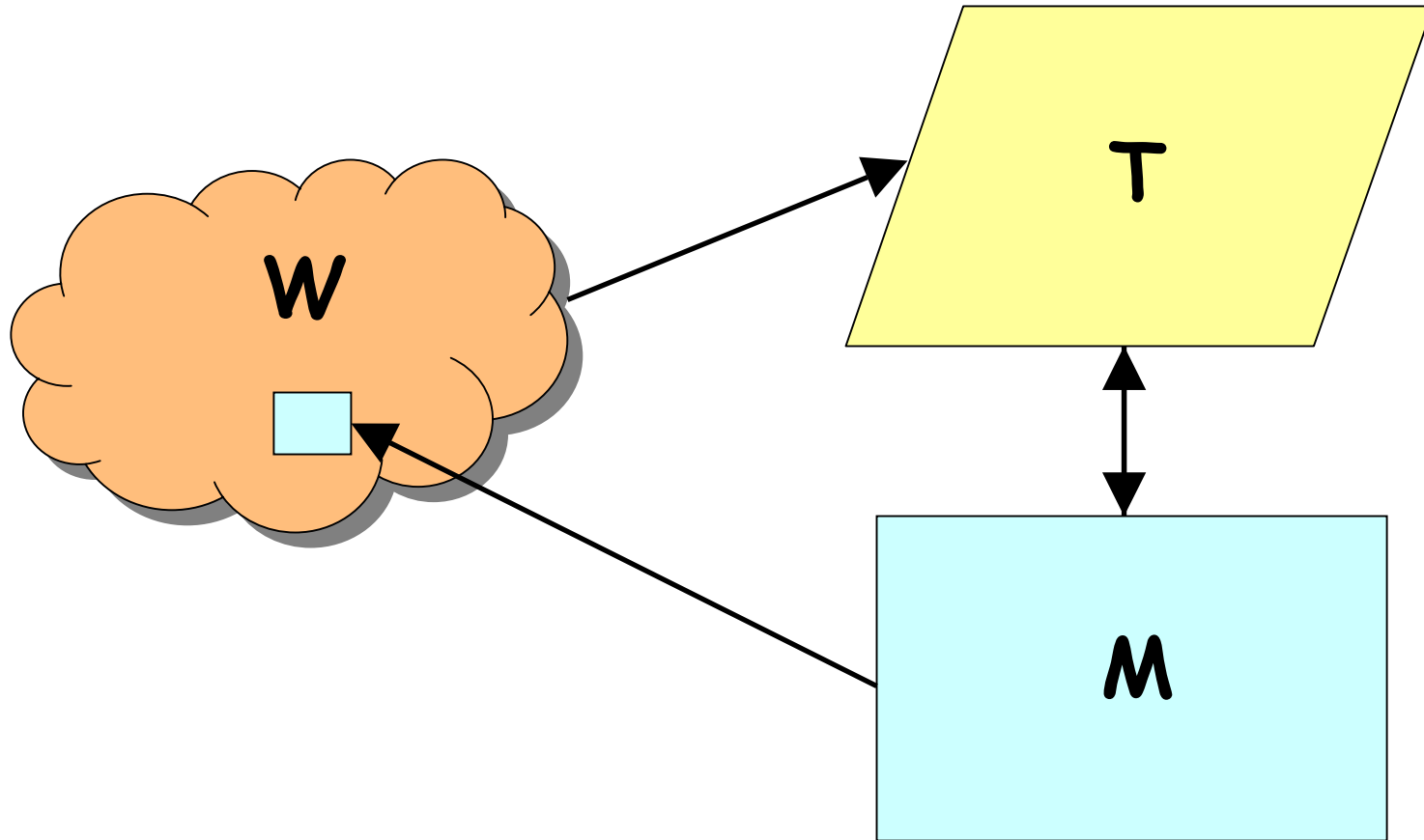
↳ Inject the model (M) into the world (W')

- Thereby changing the world

→ $W' \rightarrow T'$

↳ The changed world (W') induces changes in theory (T')

TM Simplified



Simplified Model TM

→ **W**

↳ The world - more specifically, the relevant part of the world

→ **T**

↳ The theory initiated by observation and abstraction

→ **M**

↳ A model that satisfies the theory

→ **W** → **T**

↳ Generate a theory: observe and abstract from the world (W) to create a theory (T)

↳ Adjust and extend the theory

→ **T** → **M**

↳ From theory (T) create a model (M) [T&M]

↳ Change the model to better satisfy the theory

Simplified Model TM

→ $M \rightarrow T$

↳ Change the theory to conform with the model

→ $T \rightarrow T$

↳ Frequently evolve the theory until satisfied

→ $M \rightarrow M$

↳ We frequently evolve the model until (often only temporarily) satisfied

→ $M \rightarrow W$

↳ Inject the model (M) into the world (W')

➤ Thereby changing the world

Theory MTM

- Basically applying TM to itself - ie, TM instantiated for the processes of creating and evolving TM
- We observe and abstract some specific part of the world and create a theory of
 - ↳ what the world is like
 - ↳ what form theory should take
 - ↳ what form the model should take
 - ↳ the processes of creating the theory and a model and injecting it into the world
- From that theory we create a usable model of
 - ↳ what the world is like
 - ↳ what form theory should take
 - ↳ what form the model should take
 - ↳ the processes of creating the theory and a model and injecting it into the world

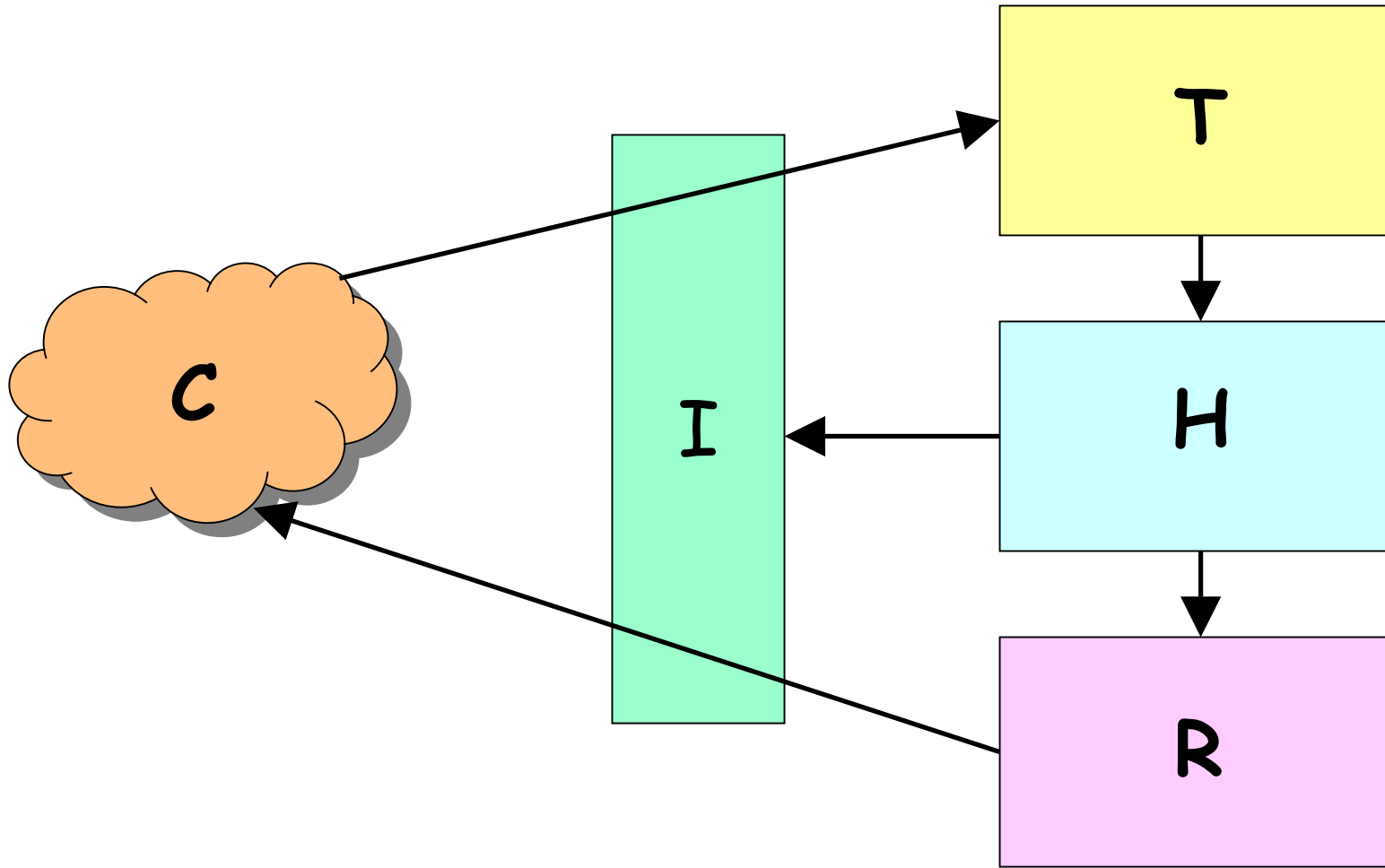
Theory MTM

- We iteratively adjust both the theory and the model as our understanding of the theory and the model evolves
- When satisfied, we inject the model into the world
- Injecting the model into the world changes the world
- These changes in the world may then lead to adjustments and extensions to the original theory
- This then leads to further changes in the model and world

Model MTM

- MW - same world W as in TM
- MT - theory of TM and its elements and processes
 - ↳ $T(W), T(T), T(M)$
 - Theories about the world, theory, and model
 - ↳ $T(W \rightarrow T), T(T \rightarrow M), T(M \rightarrow T), T(T \rightarrow T), T(M \rightarrow M), T(M \rightarrow W)$
 - Theories about the processes of creating and evolving TM and injecting it into the world
- MM - model of TM and its elements and processes
 - ↳ $M(W), M(T), M(M)$
 - The practical models of the world, theory (requirements) and model (system)
 - ↳ $M(W \rightarrow T), M(T \rightarrow M), M(M \rightarrow T), M(T \rightarrow T), M(M \rightarrow M), M(M \rightarrow W)$
 - The models (ie, the actual processes) of creating and evolving TM and injecting it into the world
- $W \rightarrow MT, MT \rightarrow MM, MM \rightarrow MT, MT \rightarrow MT, MM \rightarrow MM, MM \rightarrow W$
 - ↳ The processes of creating and evolving MT/MM and injecting it into the world

Empirical Theory - ET



Theory E

- Given a theory, generate an *hypothesis* to test some part of the theory
- From the hypothesis, generate a treatment (a *regimen* that 1) manipulates the *independent variables* and 2) uses *instruments* to observe the manipulations of the regimen on the *dependent variables* in the *context* relevant to the empirical study
- On the basis of the instrumented observations, reconcile the observations with the theory, revising the theory if needed.

Comment on E

- Simplified to basics - meant to cover the entire range of empirical studies from exploratory thru the rigorous explanatory studies
- The given theory may be
 - ↪ Vague and ill formed when doing exploratory work
 - ↪ Well formed and mature when doing explanatory work (typically H_0)
- The hypothesis may be
 - ↪ Generic and open-ended when doing exploratory work
 - ↪ Focused and specific when doing explanatory work
- The instruments and treatments may be
 - ↪ Human and opportunistic when doing exploratory work
 - ↪ Specifically and well-designed in both cases when doing explanatory work
- Reconciliation of theory and reality may be
 - ↪ Theory generation when doing exploratory work
 - ↪ Adding support for the theory or revising the theory when doing explanatory work

Model E

→ Elements

- ↪ T - Theory
- ↪ H - Hypothesis
- ↪ R - Regimen (Treatment)
- ↪ I - Instrument
- ↪ C - Context in which R is to be applied and observed by I
 - Where the independent and dependent variables are found

→ Processes (simplified)

- ↪ $T \rightarrow H$ - deriving a hypothesis H from theory T
- ↪ $H \rightarrow (I, R)$ - generating the experimental design from H
 - $H \rightarrow I$ - create appropriate mechanisms (based on H) for observing independent and dependent variables
 - $H \rightarrow R$ - create appropriate mechanisms and manipulations (based on H) of independent variables
- ↪ $(R, I) \rightarrow C$ - performing the experiment
 - $R \rightarrow C$ - applying the regimen to the context (ie, the independent variables)
 - $I \rightarrow C$ - using the instrument to observe the context (ie, the dependent variables)
- ↪ $(I, C) \rightarrow T$ - reconciling theory and reality

Applying E to TM - ETM

→ ETM1 - $E(T, H, R, I, W)$ - Theory Representativeness

↪ How well does the theory represent the the part of the world it is meant to capture

↪ R - comparison on selected criteria

↪ I - mechanisms that capture the data relative to those criteria

→ ETM2 - $E(T, H, R, I, M)$ - Model Adequacy [$E(M, H, R, I, T)$?]

↪ How well does the model represent the theory

↪ H - focuses on some part of the theory to evaluate

↪ R - Tests to exercise the model for that part

↪ I - mechanisms that provide the appropriate observations of the model to determine adequacy

→ ETM3 - $E(M, H, R, I, W)$ - Model Utility

↪ How useful is the model in the world

↪ H - focuses on some part of the model

↪ R - normal use of the model

↪ I - mechanisms that provide the appropriate observations to determine its utility

Applying E to TM

→ ETM4a - $E(W \rightarrow T, H, R, I, W)$

↳ Evaluate theory generation process

→ ETM4b - $E(W \rightarrow T, H, R, I, W)$

↳ Evaluate theory adaptation process in changing world

→ ETM5 - $E(T \rightarrow M, H, R, I, W)$

↳ Evaluate model generation of M from T process

→ ETM6 - $E(M \rightarrow T, H, R, I, W)$

↳ Evaluate process of adaptation of theory T to model M

→ ETM7 - $E(T \rightarrow T, H, R, I, W)$

↳ Evaluate process of evolving theory T

→ ETM9 - $E(M \rightarrow M, H, R, I, W)$

↳ Evaluate process of evolving model M

→ ETM10 - $E(M \rightarrow W, H, R, I, W)$

↳ Evaluate process of injecting model M into the world W

Comment

- The first three empirical studies evaluate the qualities of the theory and model with respect to
 - ↳ Adequacy of theory representing some part of the world
 - ↳ Adequacy of the model relative to the theory
 - ↳ Utility of the model in the world
- The other six empirical studies provide the means for *in process* as well as *post mortem* evaluations of the various basic processes
 - ↳ In generating and evolving the theory
 - ↳ In creating and evolving the model, and
 - ↳ Injecting it into the world

Model MTM

- **MW** - same world W as in **TM**
- **MT** - theory of **TM** and its elements and processes
 - ↳ $T(W), T(T), T(M)$
 - Theories about the world, theory, and model
 - ↳ $T(W \rightarrow T), T(T \rightarrow M), T(M \rightarrow T), T(T \rightarrow T), T(M \rightarrow M), T(M \rightarrow W)$
 - Theories about the processes of creating and evolving **TM** and injecting it into the world
- **MM** - model of **TM** and its elements and processes
 - ↳ $M(W), M(T), M(M)$
 - The practical models of the world, theory (requirements) and model (system)
 - ↳ $M(W \rightarrow T), M(T \rightarrow M), M(M \rightarrow T), M(T \rightarrow T), M(M \rightarrow M), M(M \rightarrow W)$
 - The models (ie, the actual processes) of creating and evolving **TM** and injecting it into the world
- $W \rightarrow MT, MT \rightarrow MM, MM \rightarrow MT, MT \rightarrow MT, MM \rightarrow MM, MM \rightarrow W$
 - ↳ The processes of creating and evolving **MT/MM** and injecting it into the world

Applying E to MTM - EMTM

→ EMTM1 - $E(MT, H, R, I, W)$ - Theory
Representativeness

↳ How well does the theory represent the the part of the world it is meant to capture

↳ R - comparison on selected criteria

↳ I - mechanisms that capture the data relative to those criteria

→ EMTM1a - $E(T(W), H, R, I, W)$

↳ Evaluate representativeness of the theory of world

→ EMTM1b - $E(T(T), H, R, I, W)$

↳ Evaluate representativeness of the theory of theories

→ EMTM1c - $E(T(M), H, R, I, W)$

↳ Evaluate representativeness of the theory of models

Applying E to MTM - EMTM

- EMTM1da - $E(T(W \rightarrow T), H, R, I, W)$
 - ↳ Evaluate representativeness of the theory of theory generation process
- EMTM1db - $E(T(W \rightarrow T), H, R, I, W)$
 - ↳ Evaluate representativeness of the theory of theory adaptation process in changing world
- EMTM1e - $E(T(T \rightarrow M), H, R, I, W)$
 - ↳ Evaluate representativeness of the theory of model generation of M from T process
- EMTM1f - $E(T(M \rightarrow T), H, R, I, W)$
 - ↳ Evaluate representativeness of the theory of adaptation of theory T to model M
- EMTM1g - $E(T(T \rightarrow T), H, R, I, W)$
 - ↳ Evaluate representativeness of the theory of evolving theory T
- EMTM1h - $E(T(M \rightarrow M), H, R, I, W)$
 - ↳ Evaluate representativeness of the theory of evolving M
- EMTM1i - $E(T(M \rightarrow W), H, R, I, W)$
 - ↳ Evaluate representativeness of the theory of injecting model M into the world W

Applying E to MTM - EMTM

→ EMTM2 - $E(MT, H, R, I, MM)$ - Model Adequacy

↳ How well does the model represent the theory

↳ H - focuses on some part of the theory to evaluate

↳ R - Tests to exercise the model for that part

↳ I - mechanisms that provide the appropriate observations of the model to determine adequacy

→ EMTM2a - $E(T(W), H, R, I, M(W))$

↳ Evaluate the adequacy of the model of the world

→ EMTM2b - $E(T(T), H, R, I, M(T))$

↳ Evaluate the adequacy of the model of theories

→ EMTM2c - $E(T(M), H, R, I, M(M))$

↳ Evaluate the adequacy of the model of models

Applying E to MTM - EMTM

- EMTM2da - $E(T(W \rightarrow T), H, R, I, M(W \rightarrow T))$
 ↪ Evaluate adequacy of the model of theory generation process
- EMTM2db - $E(T(W \rightarrow T), H, R, I, M(W \rightarrow T))$
 ↪ Evaluate adequacy of the model of theory adaptation process in changing world
- EMTM2e - $E(T(T \rightarrow M), H, R, I, M(T \rightarrow M))$
 ↪ Evaluate adequacy of the model of model generation of M from T process
- EMTM2f - $E(T(M \rightarrow T), H, R, I, M(M \rightarrow T))$
 ↪ Evaluate adequacy of the model of adaptation of theory T to model M
- EMTM2g - $E(T(T \rightarrow T), H, R, I, M(T \rightarrow T))$
 ↪ Evaluate adequacy of the model of evolving theory T
- EMTM2h - $E(T(M \rightarrow M), H, R, I, M(M \rightarrow M))$
 ↪ Evaluate adequacy of the model of evolving M
- EMTM2i - $E(T(M \rightarrow W), H, R, I, M(M \rightarrow W))$
 ↪ Evaluate adequacy of the model of injecting model M into the world W

Applying E to MTM - EMTM

→ EMTM3 - $E(MM, H, R, I, W)$ - Model Utility

↳ How useful is the model in the world

↳ H - focuses on some part of the model

↳ R - normal use of the model

↳ I - mechanisms that provide the appropriate observations to determine its utility

→ EMTM3a - $E(M(W), H, R, I, W)$

↳ Evaluate the utility of the model of world

→ EMTM3b - $E(M(T), H, R, I, W)$

↳ Evaluate the utility of the model of theories

→ EMTM3c - $E(M(M), H, R, I, W)$

↳ Evaluate the utility of the model of models

Applying E to MTM - EMTM

→ EMTM3da - $E(M(W \rightarrow T), H, R, I, W)$

↳ Evaluate utility of the model of theory generation process

→ EMTM3db - $E(M(W \rightarrow T), H, R, I, W)$

↳ Evaluate utility of the model of theory adaptation process in changing world

→ EMTM3e - $E(M(T \rightarrow M), H, R, I, W)$

↳ Evaluate utility of the model of model generation of M from T process

→ EMTM3f - $E(M(M \rightarrow T), H, R, I, W)$

↳ Evaluate utility of the model of adaptation of theory T to model M

→ EMTM3g - $E(M(T \rightarrow T), H, R, I, W)$

↳ Evaluate utility of the model of evolving theory T

→ EMTM3h - $E(M(M \rightarrow M), H, R, I, W)$

↳ Evaluate utility of the model of evolving M

→ EMTM3i - $E(M(M \rightarrow W), H, R, I, W)$

↳ Evaluate utility of the model of injecting model M into the world W

Applying E to MTM - EMTM

- EMTM4a - $E(W \rightarrow MT, H, R, I, W)$
 - ↳ Evaluate theory generation process
- EMTM4b - $E(W \rightarrow MT, H, R, I, W)$
 - ↳ Evaluate theory adaptation process in changing world
- EMTM5 - $E(MT \rightarrow MM, H, R, I, W)$
 - ↳ Evaluate model generation of MM from MT process
- EMTM6 - $E(MM \rightarrow MT, H, R, I, W)$
 - ↳ Evaluate process of adaptation of theory MT to model MM
- EMTM7 - $E(MT \rightarrow MT, H, R, I, W)$
 - ↳ Evaluate process of evolving theory MT
- EMTM9 - $E(MM \rightarrow MM, H, R, I, W)$
 - ↳ Evaluate process of evolving MM
- EMTM10 - $E(MM \rightarrow W, H, R, I, W)$
 - ↳ Evaluate process of injecting model MM into the world W

Applying E to itself - EE

→ EE1 - $E(H, H', R, I, T)$

↪ Evaluate H relative to T

↪ Is H relevant to T - does it have constructs appropriate to T

↪ Construct validity: intentional and representational validity

→ EE2 - $E(R, H', R', I, (H, C))$

↪ Evaluate R relative to H and C

↪ Internal validity; robustness and reliability

→ EE3 - $E(I, H', R, I', (H, C))$

↪ Evaluate I relative to H and C ; instrument artifacts

↪ Does I provide us with the ability to provide the needed measures

↪ Construct validity: representation and observational validity

→ EE4 - $E(C, H, R, I, C')$

↪ Evaluate C relative to C'

↪ C is the selected context; C' is the population context; $C \subseteq C'$

↪ External validity

→ EE5 - $E(T \rightarrow H, H', R, I, C)$

↪ Evaluate the process of deriving H from T

↪ Construct validity - intentional validity; some representational

Applying E to itself - EE

→ EE6 - $E(H \rightarrow R, H', R', I, C)$

- ↪ Evaluate the process of deriving R from H
- ↪ Internal validity and some construct validity

→ EE7 - $E(H \rightarrow I, H', R, I, C)$

- ↪ Evaluate the process of creating appropriate instruments
- ↪ Construct validity - all

→ EE8 - $E(R \rightarrow C, H, R', I, C')$

- ↪ Evaluate the process of applying the treatments to the subjects
- ↪ Internal validity

→ EE9 - $E(I \rightarrow C, H, R, I', C')$

- ↪ Evaluate the process of using the instrument to observe the treatment being applied in the context - ie the effect of the instrument on the context (process artifacts)
- ↪ Internal validity, observational validity

→ EE10 - $E(C \rightarrow T, H, R, I, C')$

- ↪ Analyze the effects of the manipulations on the subjects
- ↪ External, internal and statistical validity

→ EE11 - $E(I \rightarrow T, H, R, I', C)$

- ↪ Evaluate the analysis of instrument results - IV and SV

Comment

- Evaluation of the construct validity of E
 - ↳ EE1 - EE7, EE9
- Evaluation of the internal validity of E
 - ↳ EE6 - EE11
- Evaluation of the statistical validity of E
 - ↳ EE10 and EE11
- Evaluation of the external validity of E
 - ↳ EE10

Instantiations of TM and MTM Theories

→ System

- ↪ $T(S)$ and $M(S)$ - shorthand: TS and MS
- ↪ TS are the requirements for the software system
- ↪ MS is the resulting software system
- ↪ $MT(S)$ and $MM(S)$ - shorthand: MTS and MMS
- ↪ MTS are the requirements for the processes for creating TS and TM (ie, the requirements and system)
- ↪ MMS is the resulting process system for creating and evolving the development requirements and system

→ Development (Project Management)

- ↪ $T(D)$ and $M(D)$ - shorthand: TD and MD
- ↪ TD are the requirements for the project
- ↪ MD is the project plan
- ↪ $MT(D)$ and $MM(D)$ - shorthand: MTD and MMD
- ↪ MTD are the requirements for the processes for creating and evolving the requirements for the project and its project plans
- ↪ MMD is the resulting process system for creating and evolving the project requirements and project plans

Instantiations of TM and MTM Theories

→ Instruments

- ↪ T(I) and M(I) - shorthand: TI and MI
- ↪ TI are the requirements for the instrument
- ↪ MI is the instrument
- ↪ MT(I) and MM(I) - shorthand: MTI and MMI
- ↪ MTI are the requirements for the processes for TI and MI (ie, creating and evolving instruments)
- ↪ MMI is the resulting process system for creating and evolving instrument an its requirements

→ Empirical studies

- ↪ T(E) and M(E) - shorthand: TE and ME
- ↪ TE are the requirements for the empirical study
- ↪ TM is the empirical design/implementation
- ↪ MT(E) and MM(E) - shorthand: MTE and MME
- ↪ MTE are the requirements for processes for creating TE and ME (ie, an empirical study)
- ↪ MME is the process system for creating and evolving an empirical study - ie, the empirical design/implementation - and its requirements

Challenges

- Understand our instruments and their underlying theories thoroughly
- Explicate the theory that lies behind the models and processes
 - ↳ Make it more visible
 - ↳ So that it can be used to better advantage in empirical studies
- Establish design and design techniques for each element in the taxonomy as applied to each domain
 - ↳ $11 \times 51 \rightarrow 561$ classes in the empirical taxonomy
 - $10 \text{ ETM}^* + 41 \text{ EMTM}^* \times 11 \text{ EE}^*$
 - ↳ Applied to 4 domains: S, D, I and E \rightarrow 2244 classes of experiments
- SE is obviously a cooperative discipline
 - ↳ For systems, need domain experts
 - ↳ For processes, need behavioral scientists
 - ↳ For developments, need management experts
 - ↳ For empirical studies, need experimental experts