Title: Physical records and emergence of information in the gravitationally dominated universe

Date: May 13, 2015 09:00 AM

URL: http://pirsa.org/15050085

Abstract: The second law of thermodynamics appears to be a universal law of physics. This universality suggests that entropy and with it information theory is part of the foundations of physics.

In this talk I take the opposite (probably more conservative) approach: I assume that the dynamics of relational degrees of freedom form the foundation of physics. Physical information is an emergent phenomenon. This approach has an interesting consequence: Typical (initial) data for a gravitationally dominated universe leads to the spontaneous emergence of a gravitational arrow of time for the universe as a whole. This primary gravitational arrow of time generates secondary thermodynamic arrows of time in sufficiently isolated subsystems of the universe, which coincide with the gravitational arrow of time. This coincidence explains the universality of the second law of thermodynamics.

I conclude the talk with a speculation about the emergence of quantum information: I assume (1) that the purpose of a physical law is the prediction of future properties of the universe based on the knowledge of records and (2) that gravity generates physical records (as in the classical part of the talk). This suggests a scenario in which stable quantum information is spontaneously generated.

Collaborators for the classical part of the talk where Julian Barbour and Flavio Mercati

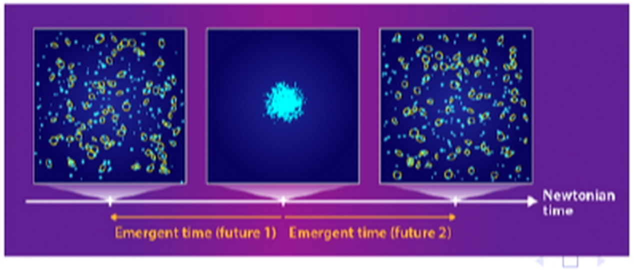
Physical records and the emergence of information in the gravitational universe

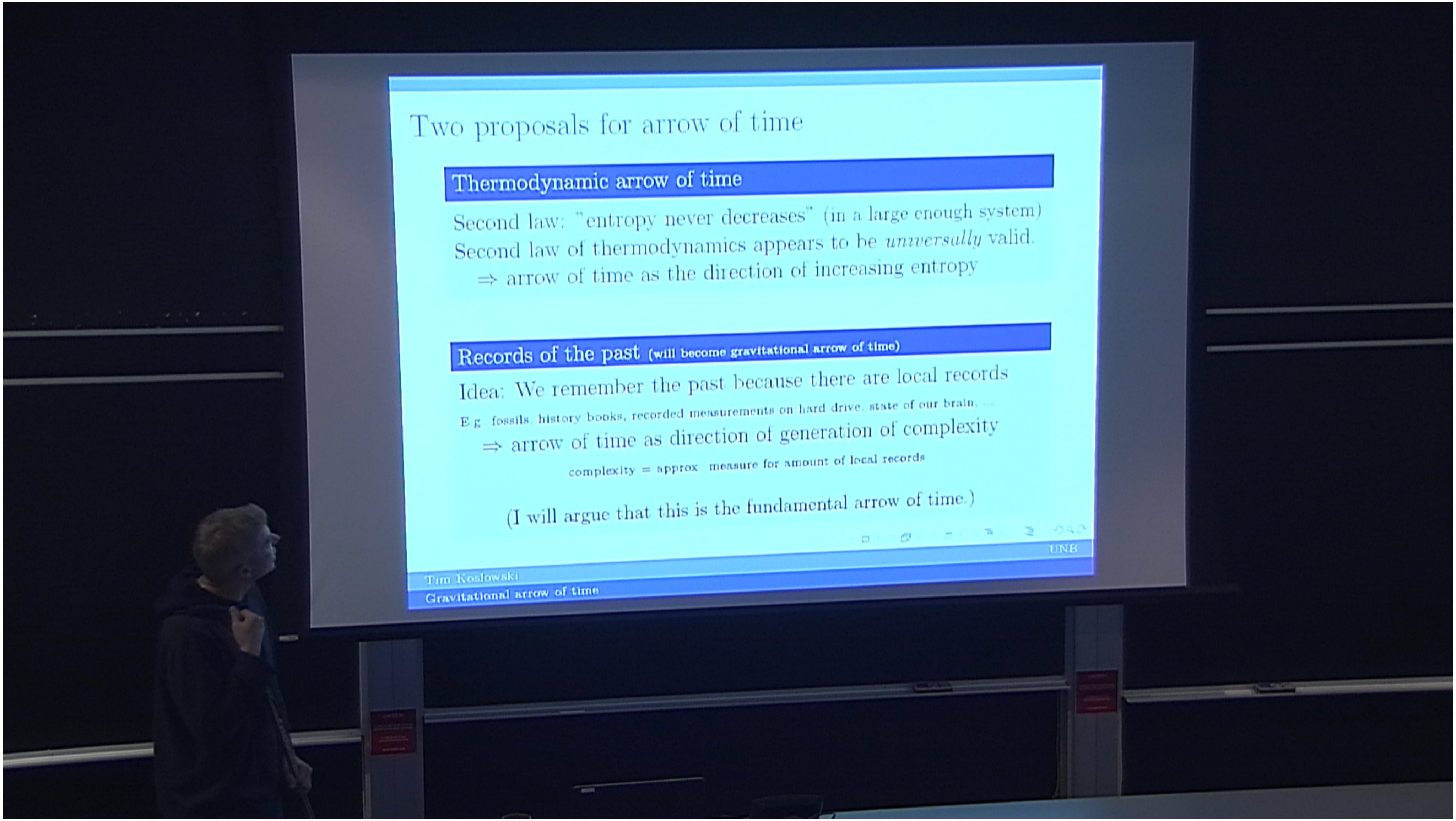
(joint work with J. Barbour and F. Mercati: PRL 113 (2014) 18, 181101)

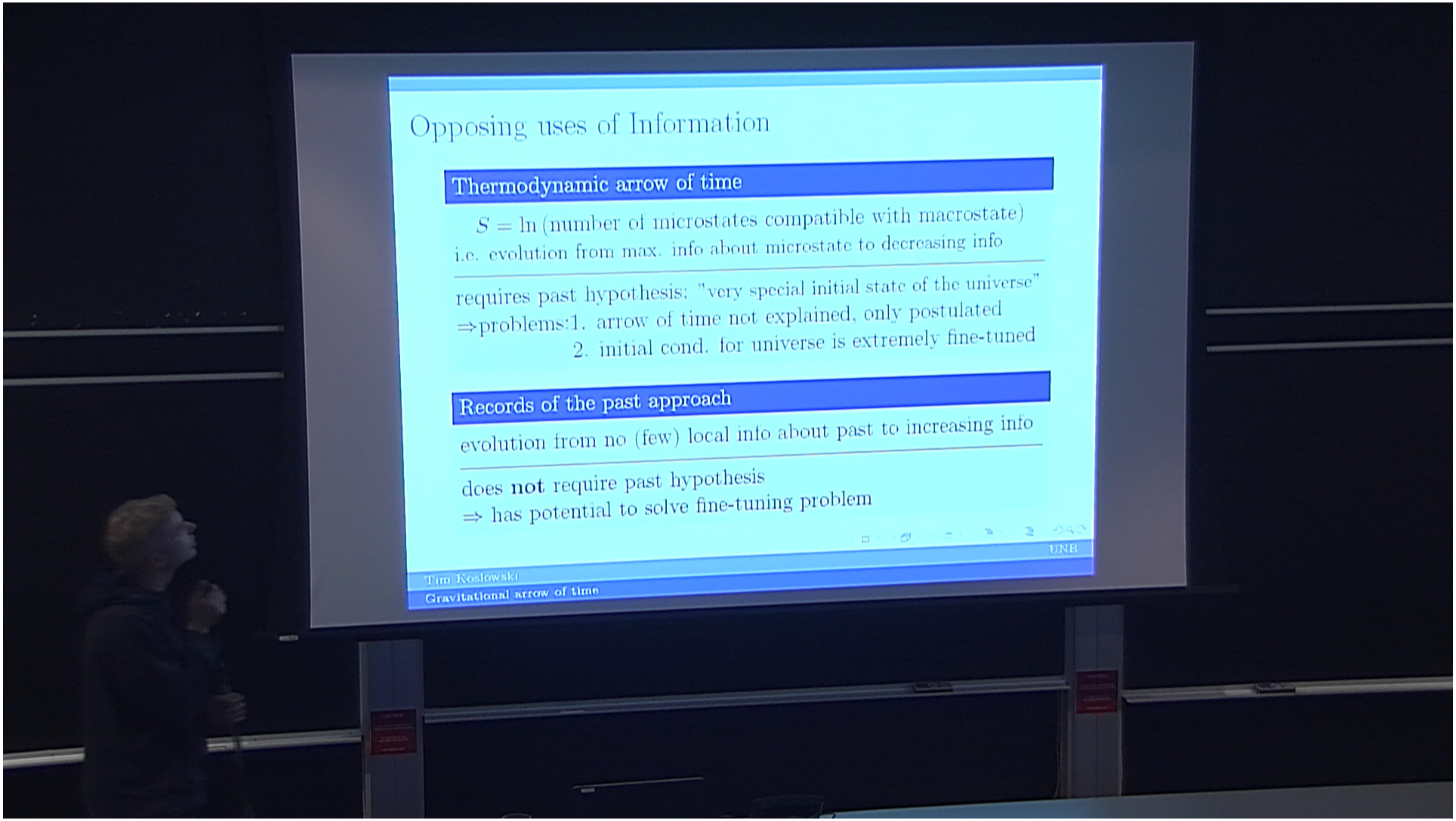
Tim A. Koslowski
t.a.koslowski@gmail.com

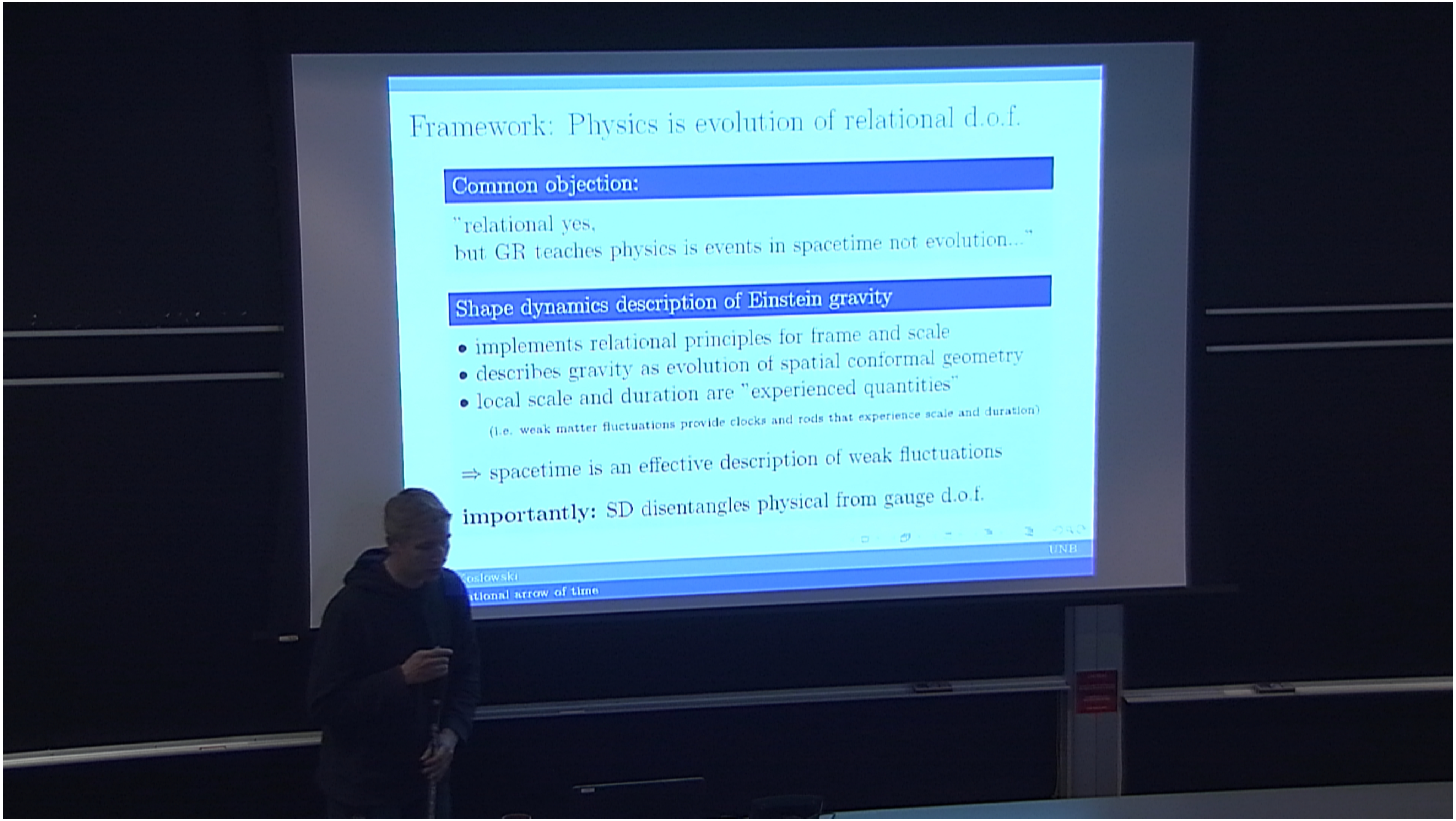
University of New Brunswick

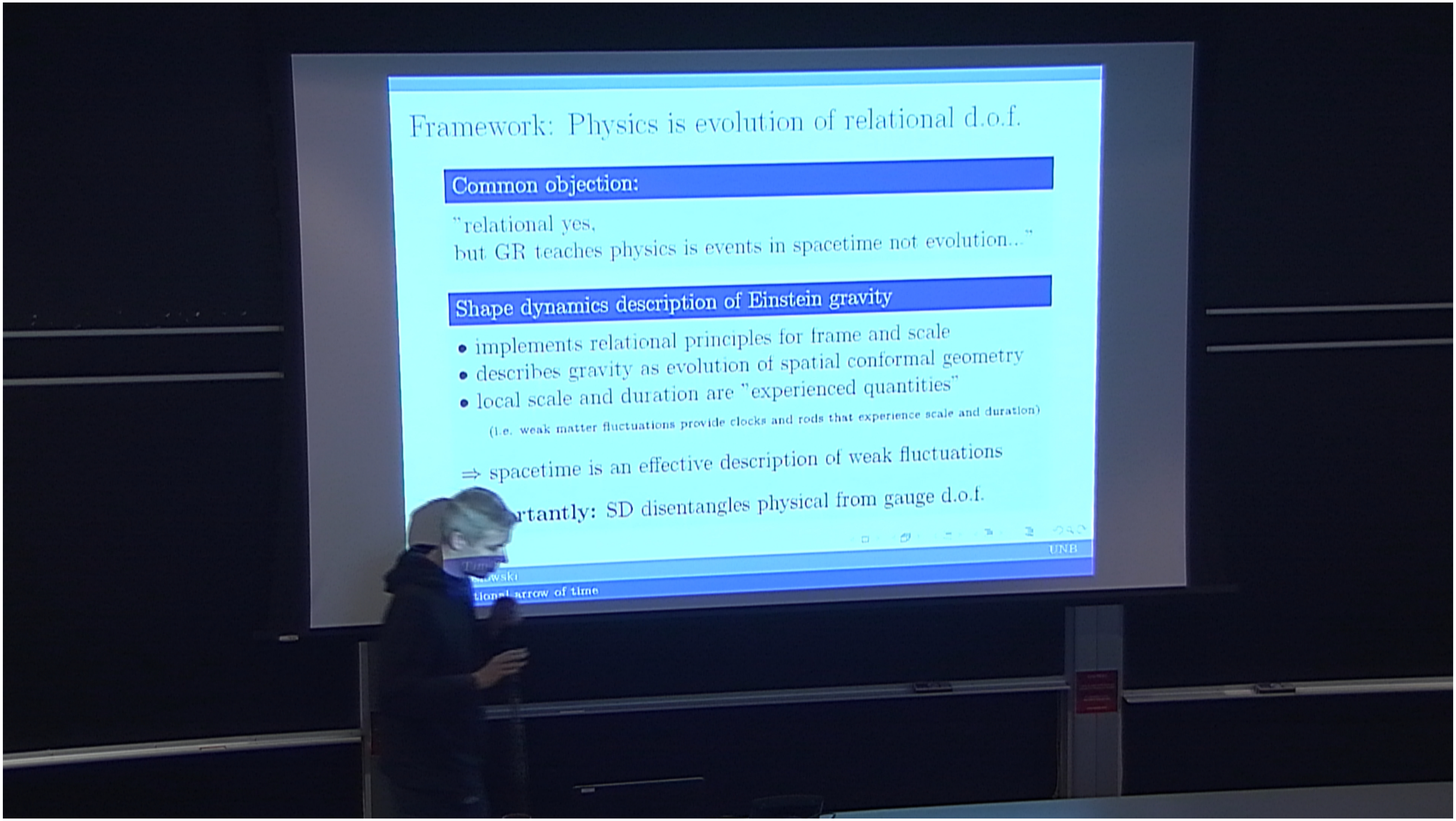
May 13, 2015

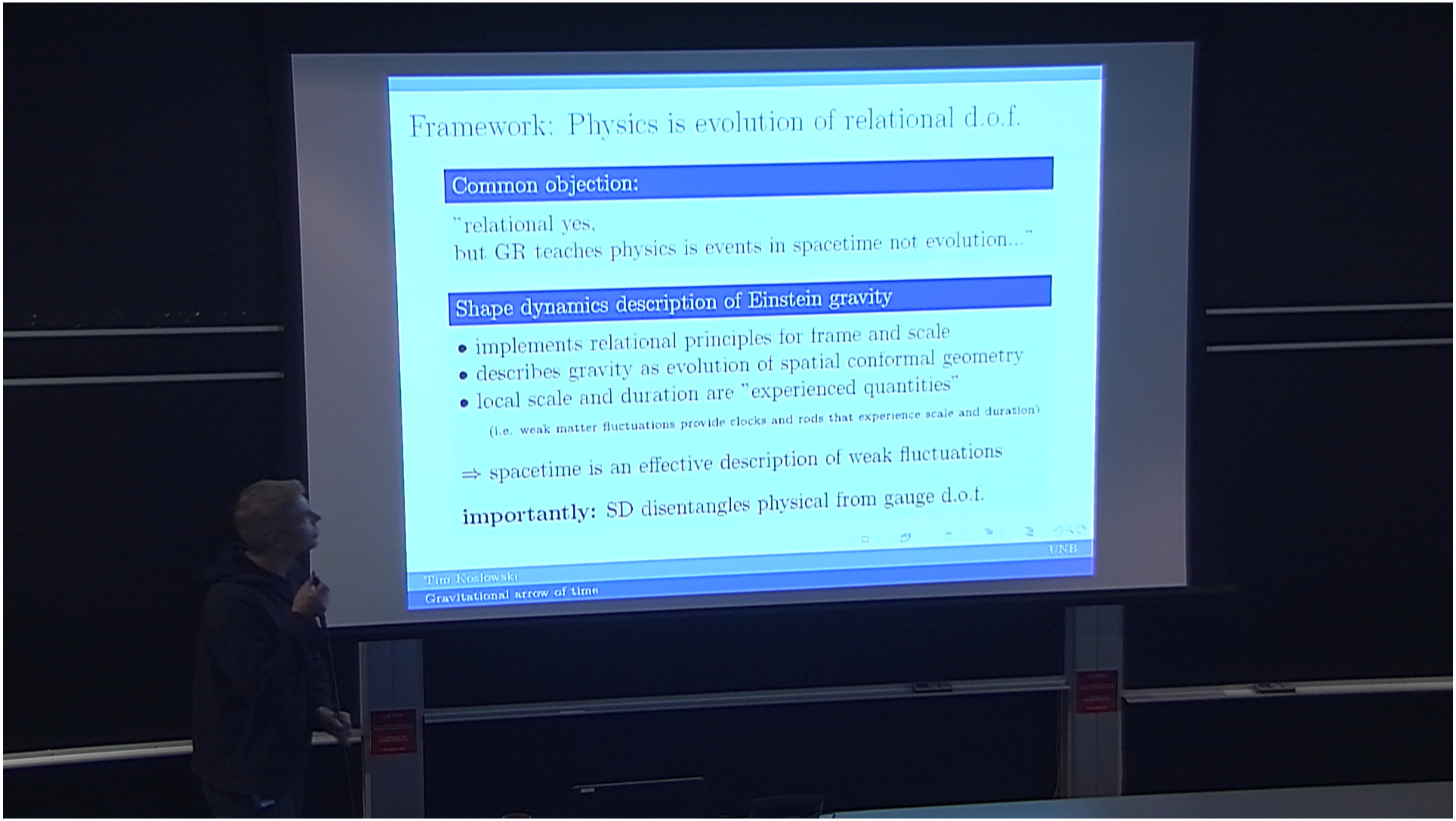


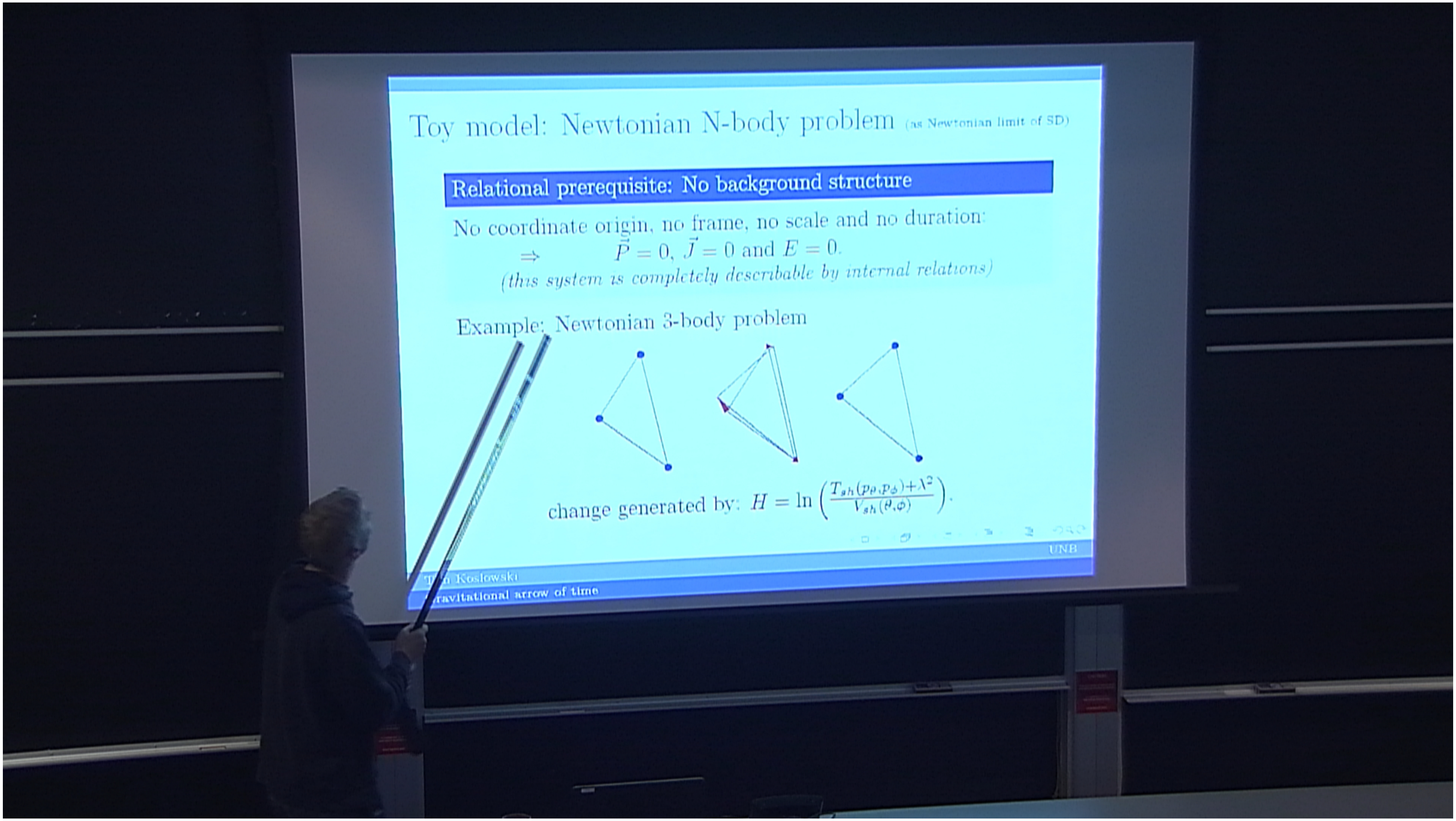

Two proposals for arrow of time
Thermodynamic arrow of time
Second law: "entropy never decreases" (in a large enough system)
Second law of thermodynamics appears to be universally valid.
⇒ arrow of time as the direction of increasing entropy
Records of the past (will become gravitational arrow of time)
Idea: We remember the past because there are local records
E.g. fossils, history books, recorded measurements on hard drive, state of our brain, ...
⇒ arrow of time as direction of generation of complexity
complexity = approx. measure for amount of local records
(I will argue that this is the fundamental arrow of time.)
UNB
Tim Koslowski
Gravitational arrow of time


Opposing uses of Information
Thermodynamic arrow of time
S = ln (number of microstates compatible with macrostate)
i.e. evolution from max. info about microstate to decreasing info
requires past hypothesis: "very special initial state of the universe"
⇒problems:1. arrow of time not explained, only postulated
2. initial cond. for universe is extremely fine-tuned
Records of the past approach
evolution from no (few) local info about past to increasing info
does not require past hypothesis
⇒ has potential to solve fine-tuning problem
UNB
Tim Koslowski
Gravitational arrow of time


Framework: Physics is evolution of relational d.o.f.
Common objection:
"relational yes,
but GR teaches physics is events in spacetime not evolution..."
Shape dynamics description of Einstein gravity
• implements relational principles for frame and scale
• describes gravity as evolution of spatial conformal geometry
• local scale and duration are "experienced quantities"
(i.e. weak matter fluctuations provide clocks and rods that experience scale and duration)
⇒ spacetime is an effective description of weak fluctuations
importantly: SD disentangles physical from gauge d.o.f.
UNB


Framework: Physics is evolution of relational d.o.f.
Common objection:
"relational yes,
but GR teaches physics is events in spacetime not evolution..."
Shape dynamics description of Einstein gravity
• implements relational principles for frame and scale
• describes gravity as evolution of spatial conformal geometry
• local scale and duration are "experienced quantities"
(i.e. weak matter fluctuations provide clocks and rods that experience scale and duration)
⇒ spacetime is an effective description of weak fluctuations
rtantly: SD disentangles physical from gauge d.o.f.
UNB
arrow of time


Framework: Physics is evolution of relational d.o.f.
Common objection:
"relational yes,
but GR teaches physics is events in spacetime not evolution..."
Shape dynamics description of Einstein gravity
• implements relational principles for frame and scale
• describes gravity as evolution of spatial conformal geometry
• local scale and duration are "experienced quantities"
(i.e. weak matter fluctuations provide clocks and rods that experience scale and duration)
⇒ spacetime is an effective description of weak fluctuations
importantly: SD disentangles physical from gauge d.o.f.
UNB
Tim Koslowski
Gravitational arrow of time


Toy model: Newtonian N-body problem (as Newtonian limit of SD)
Relational prerequisite: No background structure
No coordinate origin, no frame, no scale and no duration:
$\Rightarrow \quad \vec{P} = 0,\ \vec{J} = 0$ and $E = 0$.
(this system is completely describable by internal relations)
Example: Newtonian 3-body problem
change generated by: $H = \ln\left(\frac{T_{sh}(p_\theta, p_\phi) + \lambda^2}{V_{sh}(\theta, \phi)}\right)$.
UNB
Koslowski
arrow of time

Toy model: Newtonian N-body problem (as Newtonian limit of SD)

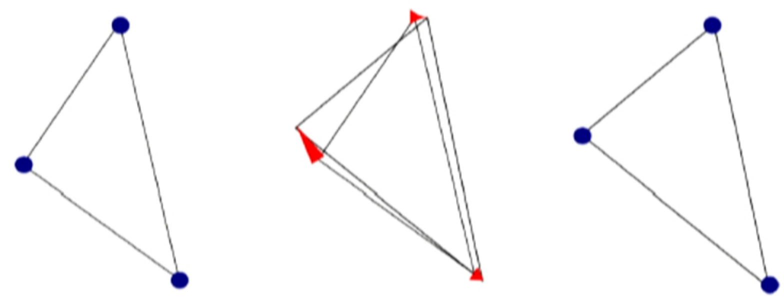
Relational prerequisite: No background structure

No coordinate origin, no frame, no scale and no duration:

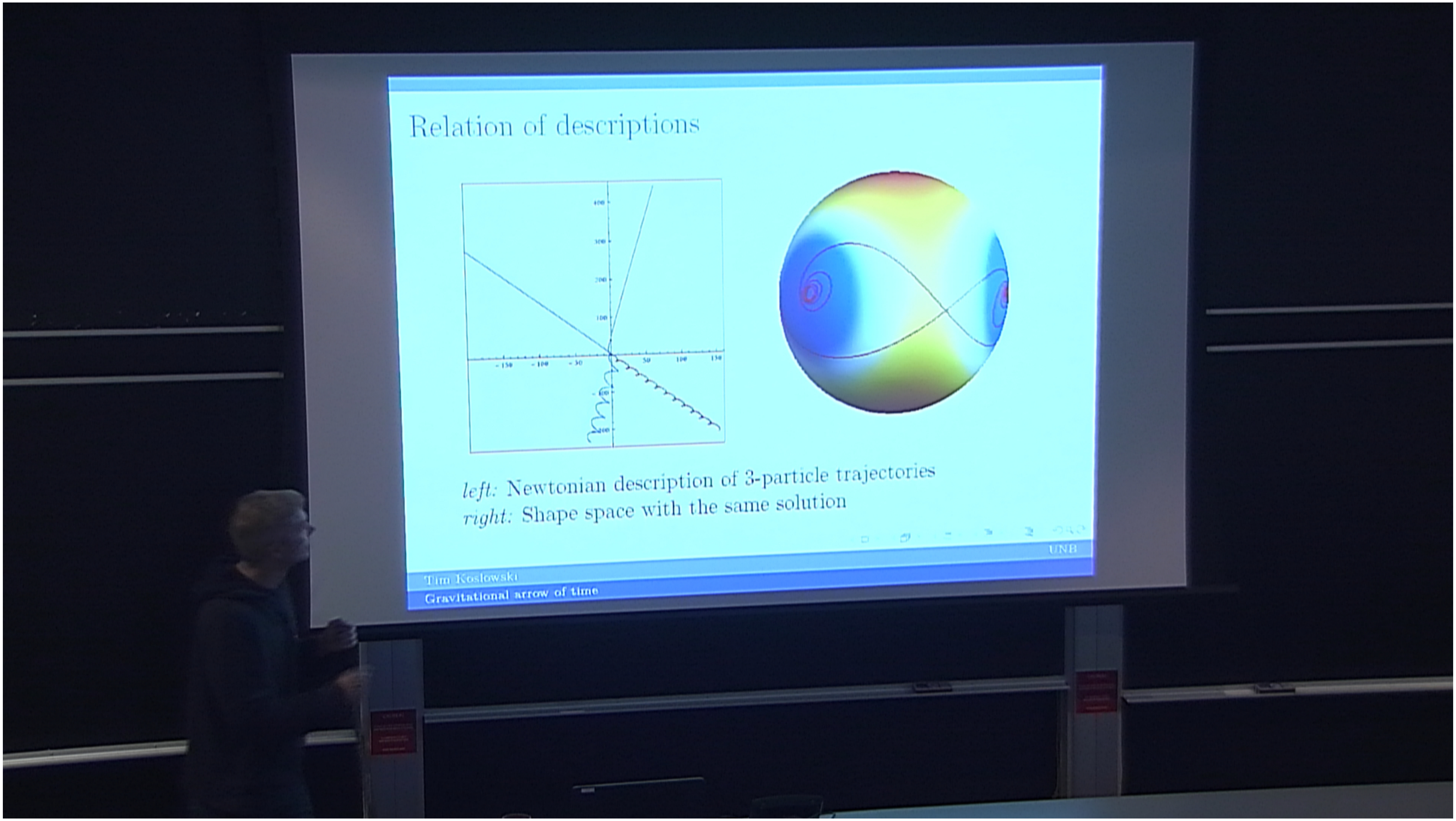
$$\Rightarrow \qquad \vec{P} = 0,\ \vec{J} = 0 \text{ and } E = 0.$$

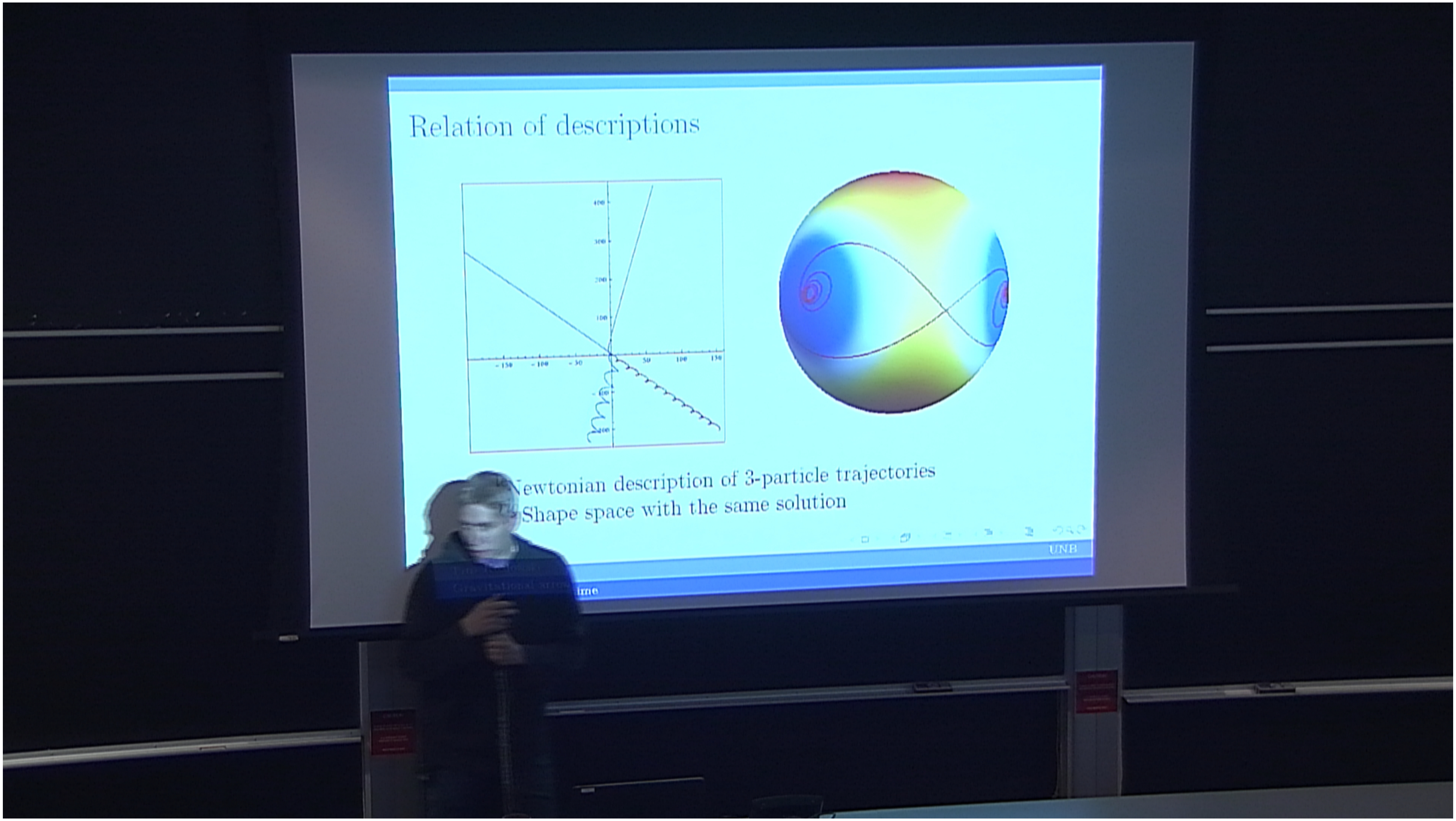
(this system is completely describable by internal relations)

Example: Newtonian 3-body problem

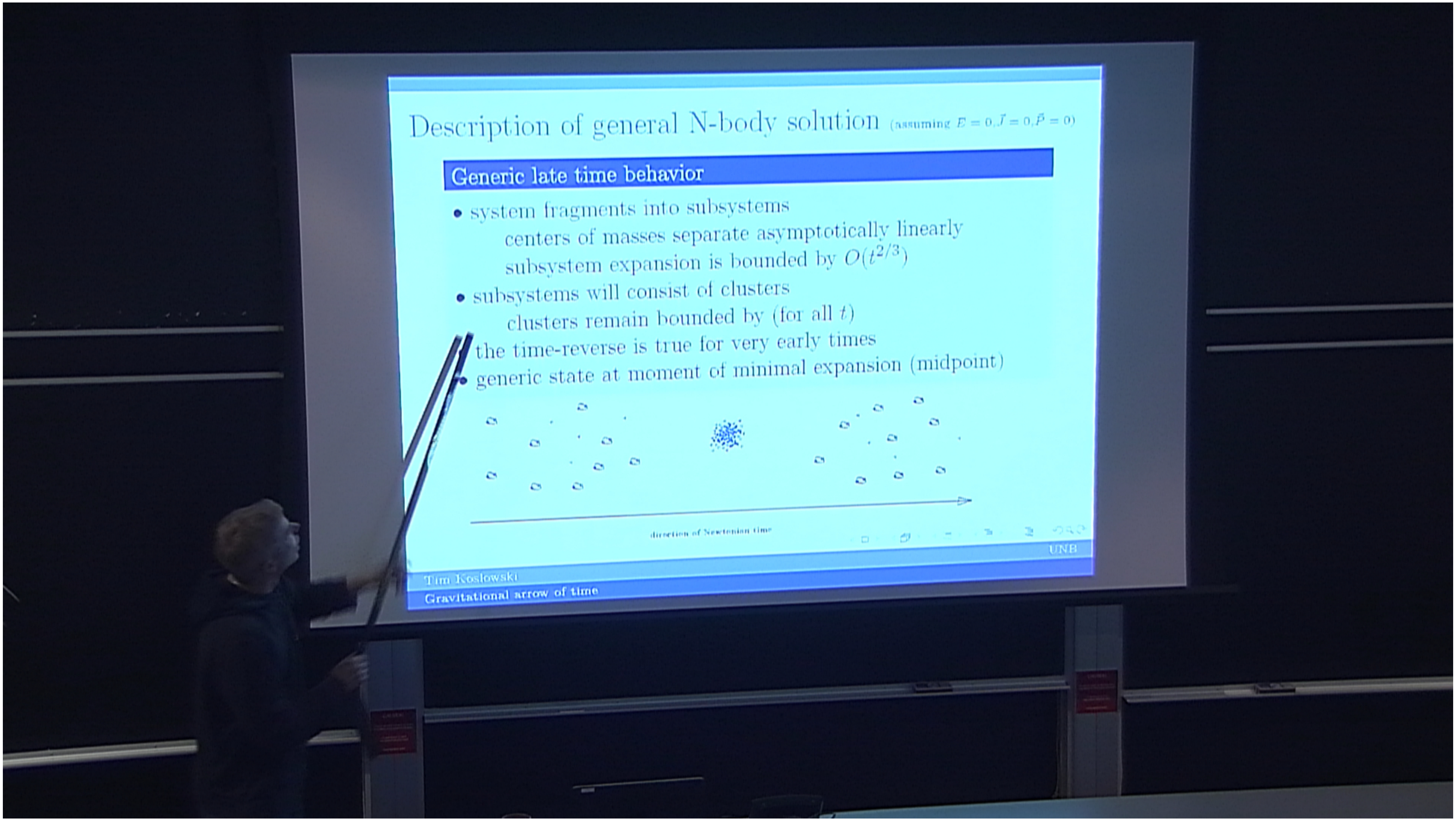


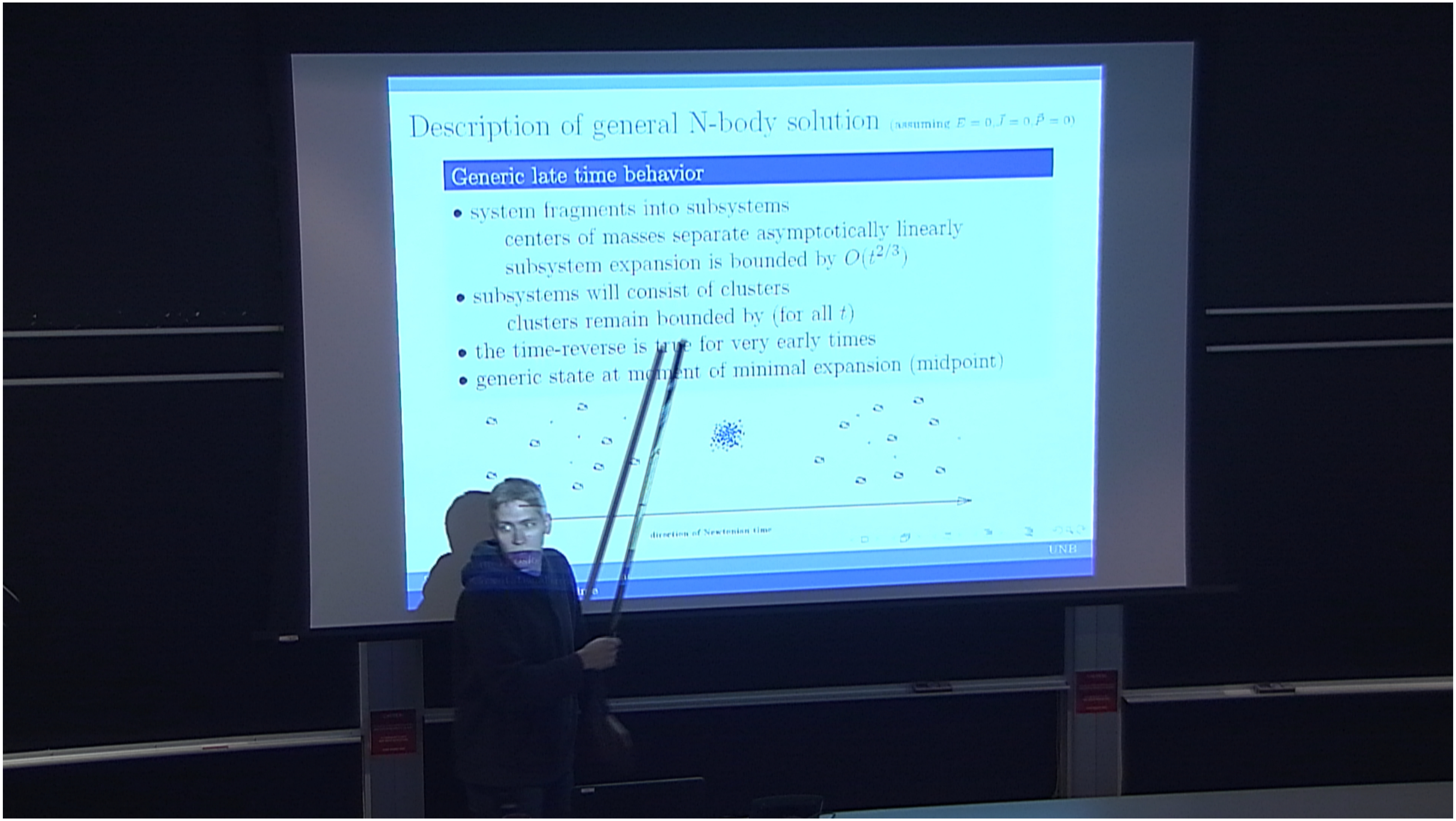
change generated by: $H = \ln\left(\frac{T_{sh}(p_\theta, p_\phi) + \lambda^2}{V_{sh}(\theta, \phi)}\right)$.

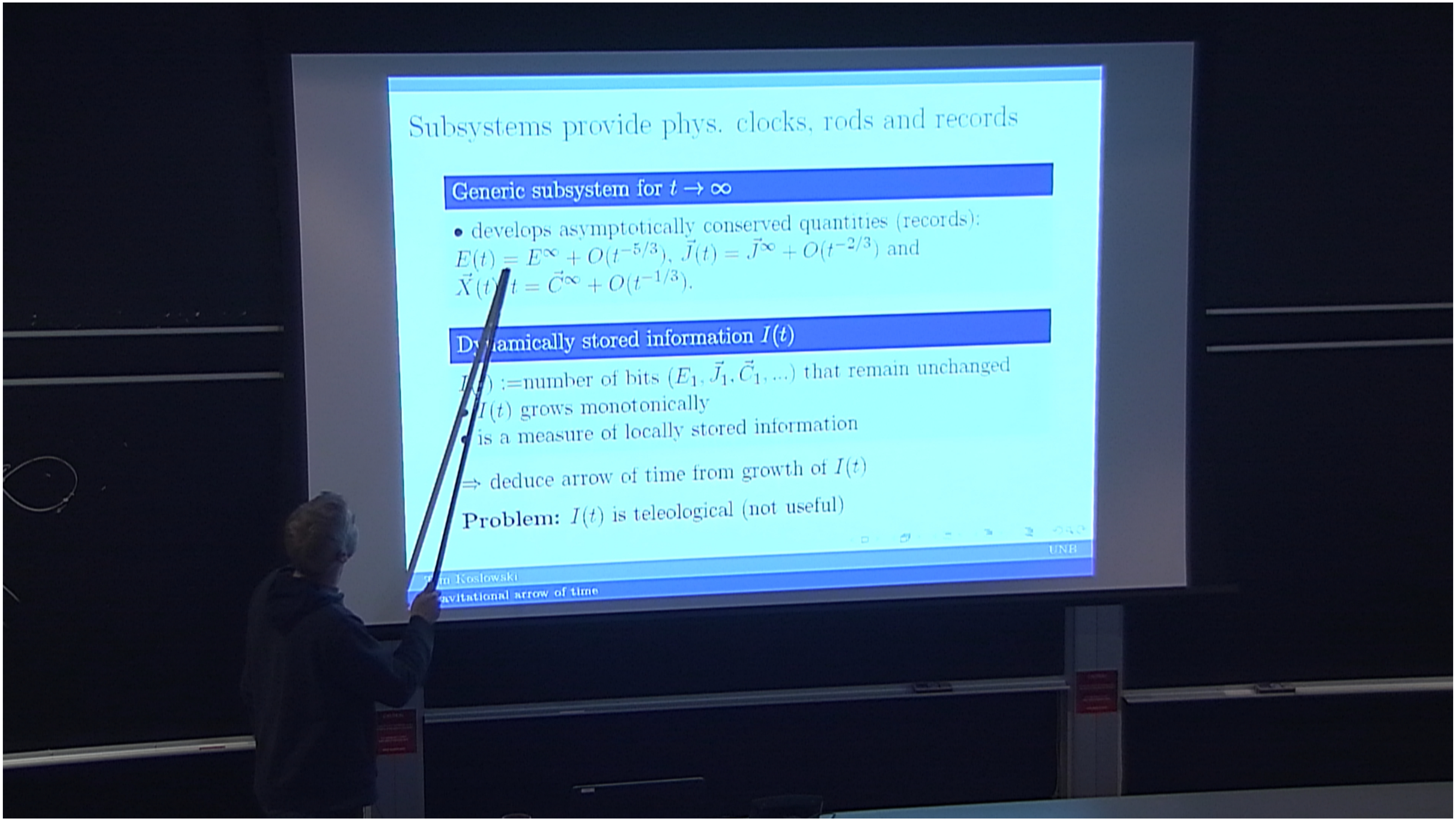

Relation of descriptions
left: Newtonian description of 3-particle trajectories
right: Shape space with the same solution
UNB
Tim Koslowski
Gravitational arrow of time


Relation of descriptions
Newtonian description of 3-particle trajectories
Shape space with the same solution
UNB


-150
left: New
right: Sh
Tim Koslowski
Gravitational arrow


Description of general N-body solution (assuming $E=0, \vec{J}=0, \vec{P}=0$)
Generic late time behavior
• system fragments into subsystems
centers of masses separate asymptotically linearly
subsystem expansion is bounded by $O(t^{2/3})$
• subsystems will consist of clusters
clusters remain bounded by (for all t)
• the time-reverse is true for very early times
• generic state at moment of minimal expansion (midpoint)
direction of Newtonian time
UNB
Tim Koslowski
Gravitational arrow of time


Description of general N-body solution (assuming $E = 0, \vec{J} = 0, \vec{P} = 0$)
Generic late time behavior
• system fragments into subsystems
centers of masses separate asymptotically linearly
subsystem expansion is bounded by $O(t^{2/3})$
• subsystems will consist of clusters
clusters remain bounded by (for all t)
• the time-reverse is true for very early times
• generic state at moment of minimal expansion (midpoint)
direction of Newtonian time
UNB


Subsystems provide phys. clocks, rods and records
Generic subsystem for $t \to \infty$
• develops asymptotically conserved quantities (records):
$E(t) = E^\infty + O(t^{-5/3})$, $\vec{J}(t) = \vec{J}^\infty + O(t^{-2/3})$ and
$\vec{X}(t)/t = \vec{C}^\infty + O(t^{-1/3})$.
amically stored information $I(t)$
) :=number of bits $(E_1, \vec{J}_1, \vec{C}_1, ...)$ that remain unchanged
$I(t)$ grows monotonically
is a measure of locally stored information
$\Rightarrow$ deduce arrow of time from growth of $I(t)$
Problem: $I(t)$ is teleological (not useful)
UNB
Koslowski
avitational arrow of time

Subsystems provide phys. clocks, rods and records

Generic subsystem for $t \to \infty$

- develops asymptotically conserved quantities (records):

$E(t) = E^\infty + O(t^{-5/3})$, $\vec{J}(t) = \vec{J}^\infty + O(t^{-2/3})$ and $\vec{X}(t)/t = \vec{C}^\infty + O(t^{-1/3})$.

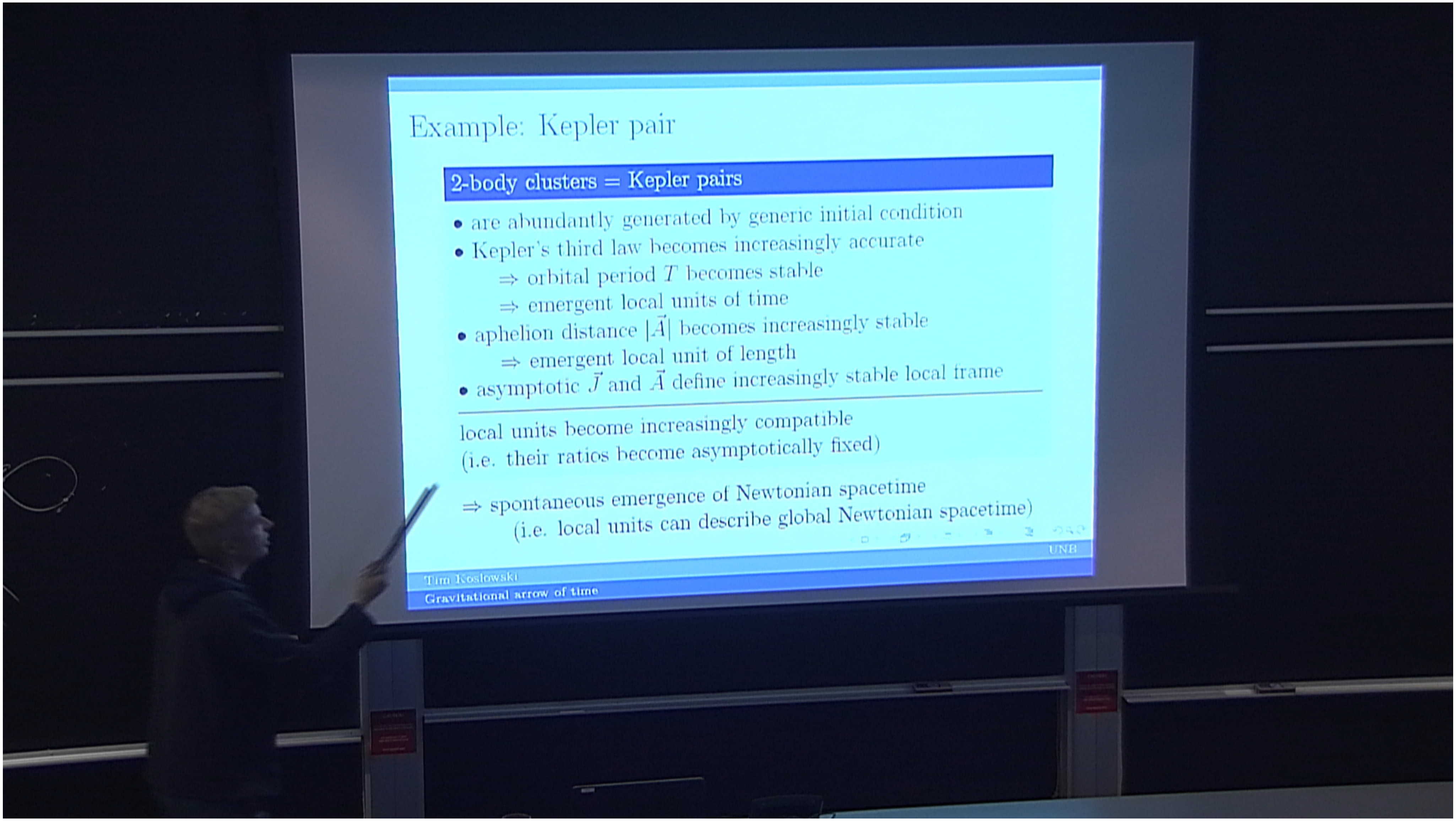
Dynamically stored information $I(t)$

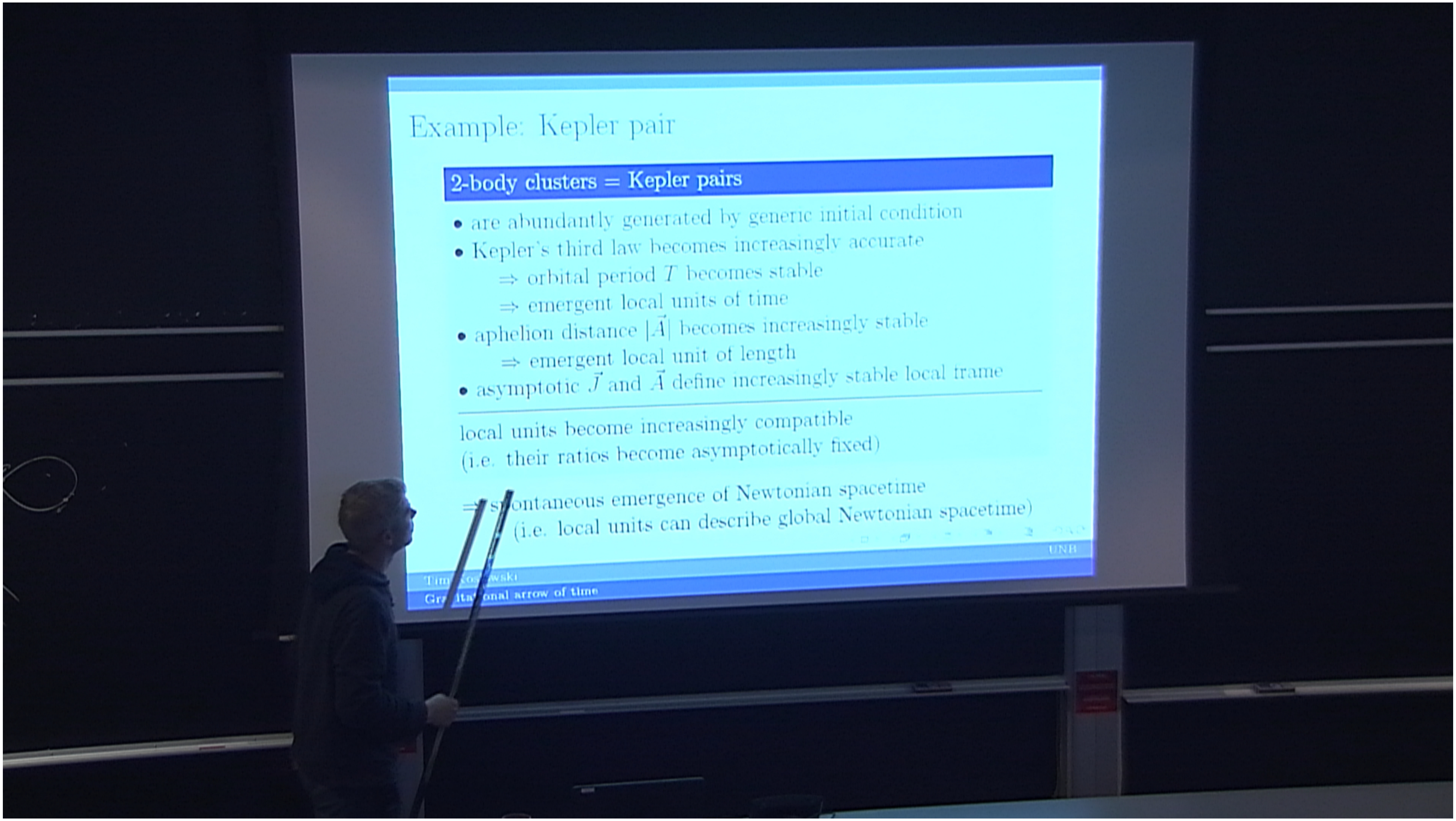
$I(t)$:=number of bits $(E_1, \vec{J}_1, \vec{C}_1, \ldots)$ that remain unchanged

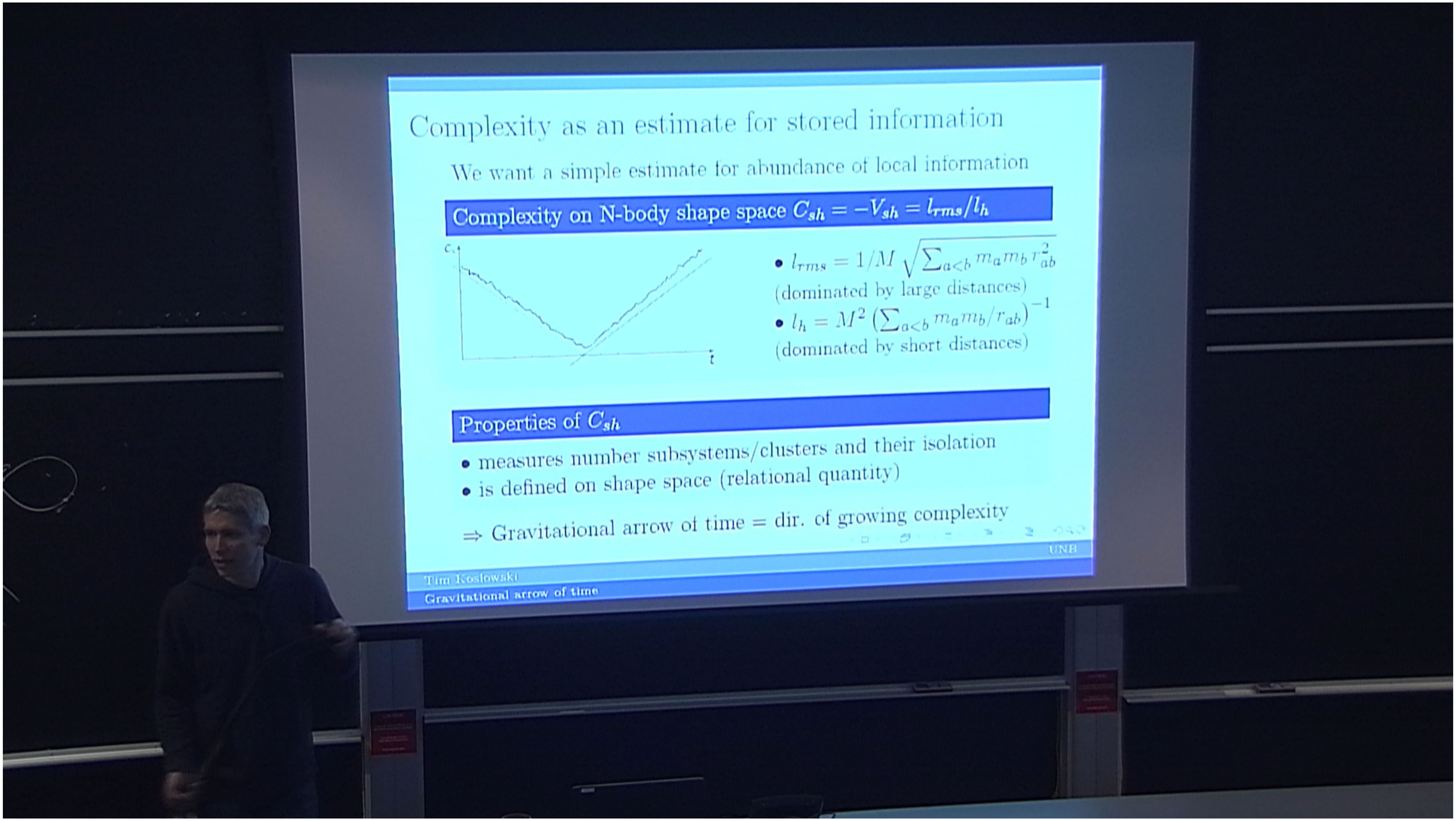
- $I(t)$ grows monotonically
- is a measure of locally stored information

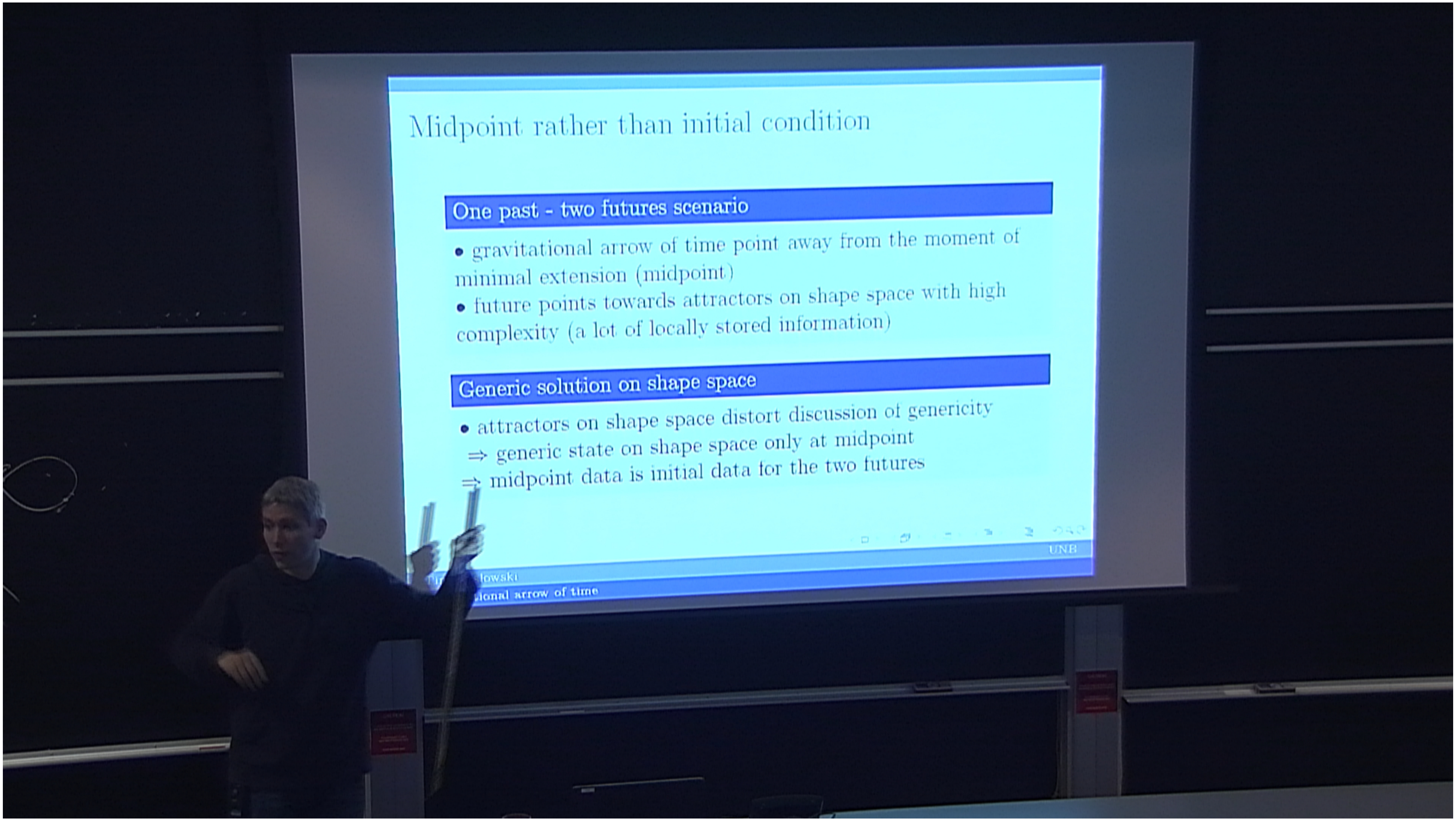
$\Rightarrow$ deduce arrow of time from growth of $I(t)$

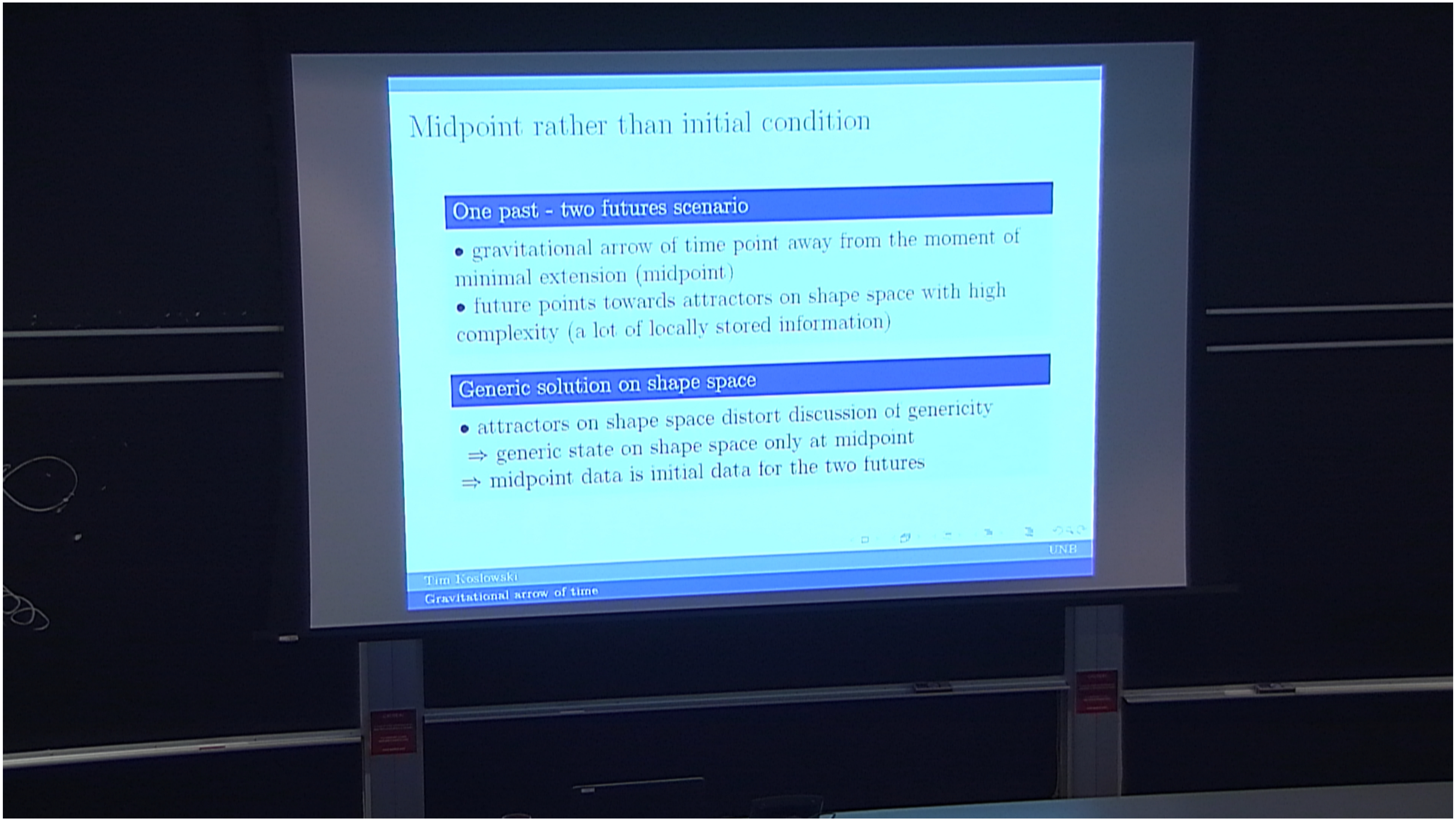
Problem: $I(t)$ is teleological (not useful)

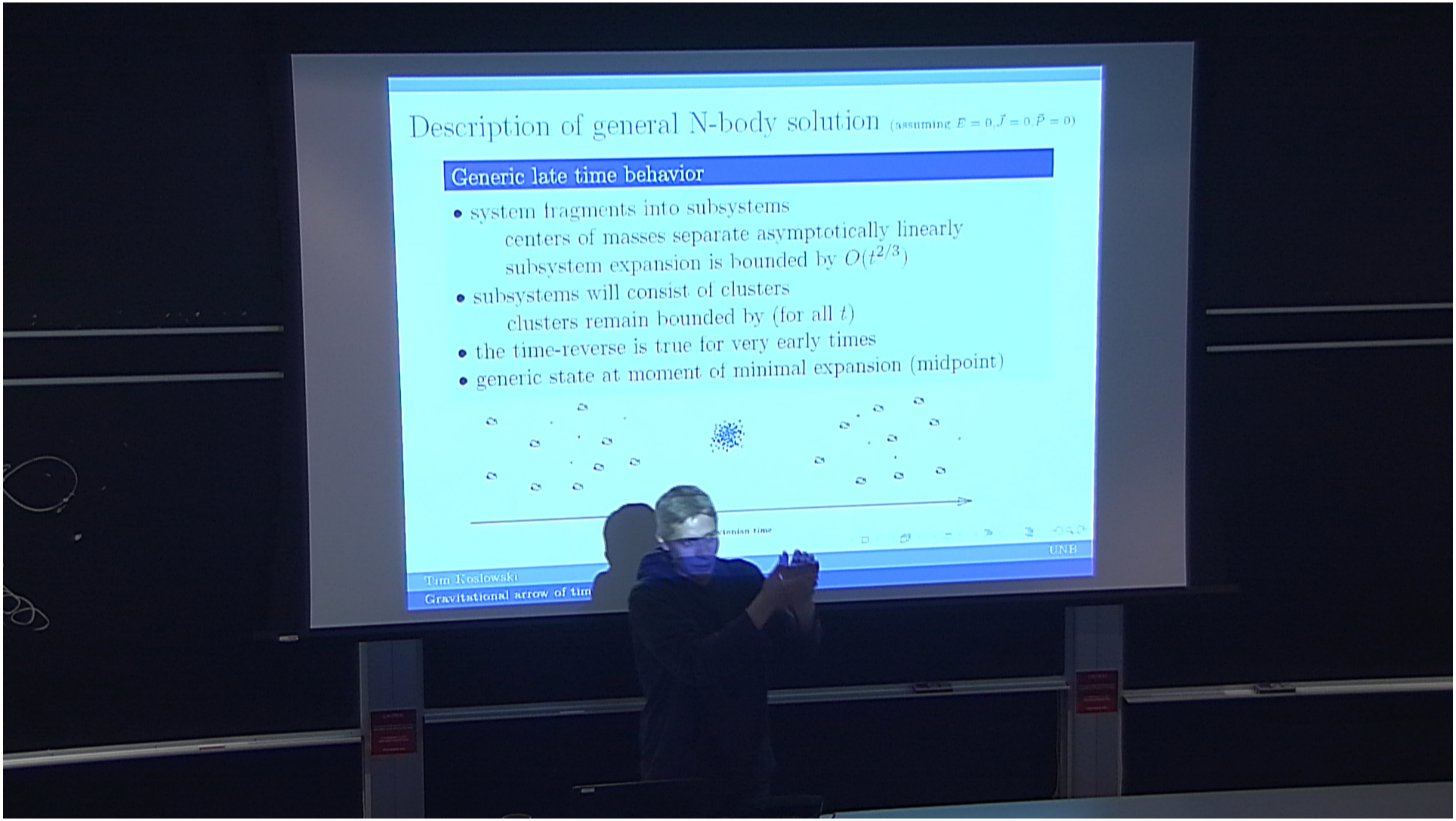

Example: Kepler pair
2-body clusters = Kepler pairs
• are abundantly generated by generic initial condition
• Kepler's third law becomes increasingly accurate
⇒ orbital period T becomes stable
⇒ emergent local units of time
• aphelion distance $|\vec{A}|$ becomes increasingly stable
⇒ emergent local unit of length
• asymptotic $\vec{J}$ and $\vec{A}$ define increasingly stable local frame
local units become increasingly compatible
(i.e. their ratios become asymptotically fixed)
⇒ spontaneous emergence of Newtonian spacetime
(i.e. local units can describe global Newtonian spacetime)
UNB
Tim Koslowski
Gravitational arrow of time


Example: Kepler pair
2-body clusters = Kepler pairs
• are abundantly generated by generic initial condition
• Kepler's third law becomes increasingly accurate
⇒ orbital period T becomes stable
⇒ emergent local units of time
• aphelion distance $|\vec{A}|$ becomes increasingly stable
⇒ emergent local unit of length
• asymptotic $\vec{J}$ and $\vec{A}$ define increasingly stable local frame
local units become increasingly compatible
(i.e. their ratios become asymptotically fixed)
⇒ spontaneous emergence of Newtonian spacetime
(i.e. local units can describe global Newtonian spacetime)
UNB


Complexity as an estimate for stored information
We want a simple estimate for abundance of local information
Complexity on N-body shape space $C_{sh} = -V_{sh} = l_{rms}/l_h$
C_s
t
• $l_{rms} = 1/M \sqrt{\sum_{a<b} m_a m_b r_{ab}^2}$
(dominated by large distances)
• $l_h = M^2 \left(\sum_{a<b} m_a m_b / r_{ab}\right)^{-1}$
(dominated by short distances)
Properties of C_{sh}
• measures number subsystems/clusters and their isolation
• is defined on shape space (relational quantity)
$\Rightarrow$ Gravitational arrow of time = dir. of growing complexity
UNB
Tim Koslowski
Gravitational arrow of time


Midpoint rather than initial condition
One past - two futures scenario
• gravitational arrow of time point away from the moment of minimal extension (midpoint)
• future points towards attractors on shape space with high complexity (a lot of locally stored information)
Generic solution on shape space
• attractors on shape space distort discussion of genericity
⇒ generic state on shape space only at midpoint
⇒ midpoint data is initial data for the two futures
UNB


Midpoint rather than initial condition
One past - two futures scenario
• gravitational arrow of time point away from the moment of minimal extension (midpoint)
• future points towards attractors on shape space with high complexity (a lot of locally stored information)
Generic solution on shape space
• attractors on shape space distort discussion of genericity
⇒ generic state on shape space only at midpoint
⇒ midpoint data is initial data for the two futures
UNB
Tim Koslowski
Gravitational arrow of time



Description of general N-body solution (assuming $E = 0, \vec{J} = 0, \vec{P} = 0$)
Generic late time behavior
• system fragments into subsystems
centers of masses separate asymptotically linearly
subsystem expansion is bounded by $O(t^{2/3})$
• subsystems will consist of clusters
clusters remain bounded by (for all t)
• the time-reverse is true for very early times
• generic state at moment of minimal expansion (midpoint)
Tim Koslowski
UNB