

Looking at the World
Sideways

Craig Callender
UCSD

1. The Problem of Time

MANIFEST TIME

- global shared Now
- updating Past, Present, Future
- Direction
- Flow
- Independent of Matter
- Productive
- Etc

PHYSICAL TIME

Many theories, so many temporal structures...

es. $\langle M^4, g, B, \text{sim} \rangle$

but all of them lack many central features of MT.

THE PROBLEM: "TWO" TIMES NEED TO BE RECONCILED

COMPARE WITH EDDINGTON'S "TWO TABLES":

MACRO



- Solid
- Substantial
- rigid
- brown

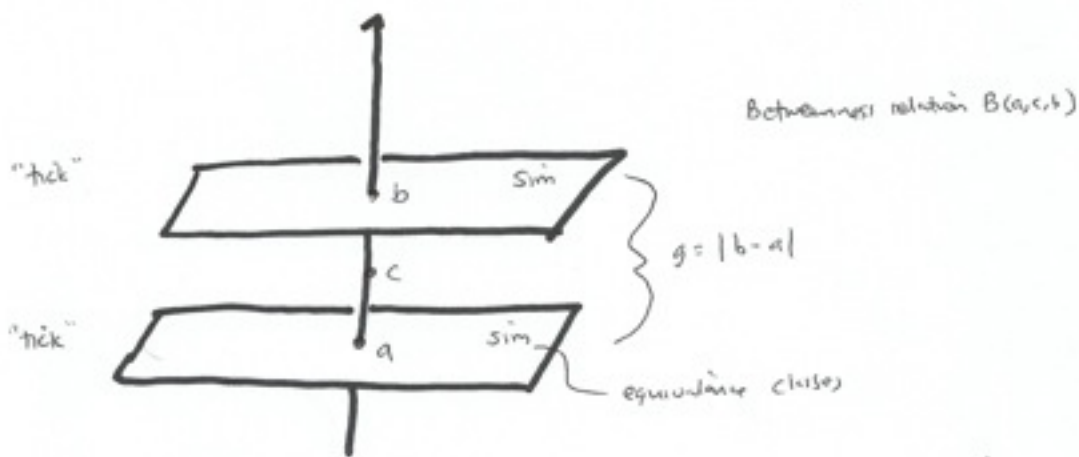
micro



- empty space, mostly
- uncolored
- not rigid, solid, etc.

AND TRY TO TELL SIMILAR RECONCILIATION STORY...

2. EXAMPLE : CLASSICAL TIME



Time is linearly ordered quotient set corresponding to simultaneity equivalence relation : $\langle M, g, B, \text{sim} \dots \rangle$

No now, no tensor triplet structure, no flow, no direction, etc.

But: if a foliation is a possible necessary condition for some of these features, then classical physics does have a distinguished one.
Not friendly to MT, but could be worse ...

But: "friendliness" depends on property and formulation. If 'independence from matter distribution' is part of MT, and one considers Cartan formulation, wherein $\nabla^2 q = 4\pi G\rho$ goes to $R_{ab} = 4\pi G\rho_a t_b$, then matter distribution affects the ticking of the master clock.

$\rho =$ distribution
to time metric

3. The Threat from Relativity (Well-known)

Two temporal structures:

Coordinate time : in Minkowski spacetime, "natural" coordinate of an inertial observer who takes herself to be at rest.

$\langle M', B \rangle \sim$ no metric features

proper time : $\tau = \int_P (g_{\mu\nu} dx^\mu dx^\nu) dP$

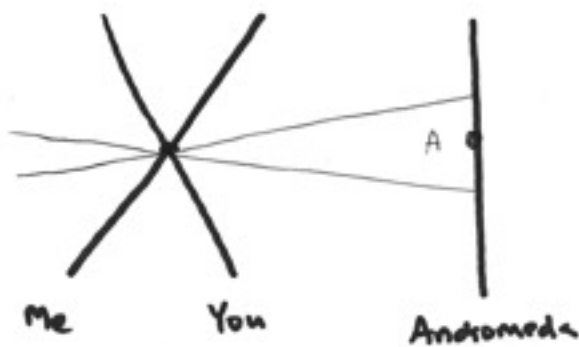


CLOCK HYPOTHESIS : Ideal clocks measure τ

$\langle M', g, B \rangle$

Do either of these times fit with MT?

- not even close



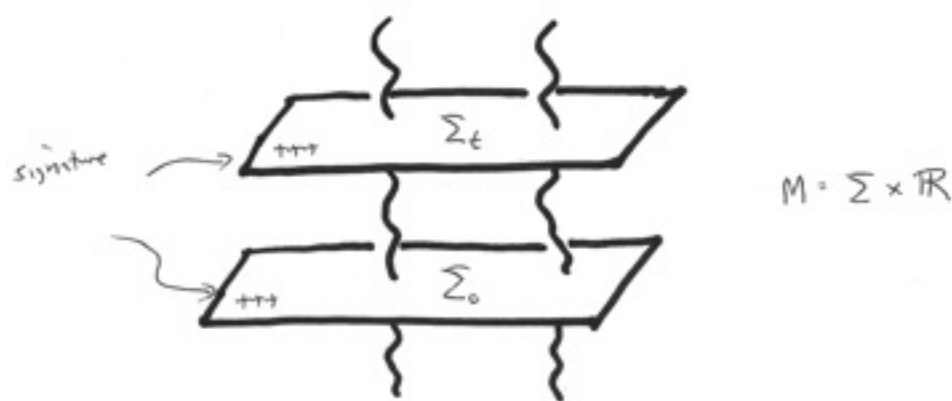
Is event A in the Past or Future?

Putnam-style argument

- Vingard
- Stein
- Callender
- Savitt

Upshot: would need to add structure

4. A "MARKOVIAN" OR "PRODUCTIVE" PICTURE OF THE WORLD



3-dimensional spatial objects and slices marching forward, screening off previous states and determining later ones

Philosophers :

- Maudlin : "The passage of time underwrites claims about one state "coming out of" or "being produced by" another, while a generic spatial... asymmetry would not underwrite such locutions"
- Tooley : the direction of time \sim direction of causation



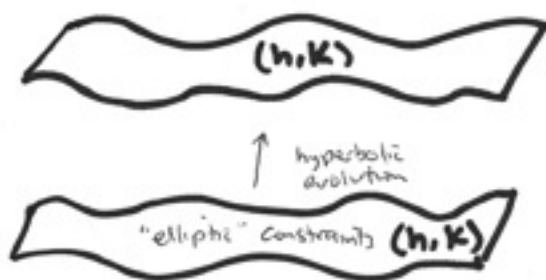
IN RELATIVITY, DESPITE ALL THE CHALLENGES TO MT, A "PRODUCTIVE" PICTURE SEEMS LIKE IT CAN BE MAINTAINED ...

- WELL, SO LONG AS WE IGNORE SOLUTIONS WHERE IT CAN'T BE, E.G. GÖDEL SPACETIME

INDEED, THE NON PLUS ULTRA OF PRODUCTION EVEN SOMETIMES HOLDS, I.E., A WELL-POSED CAUCHY PROBLEM

- a. existence of Solution
 - b. uniqueness of Solution
 - c. continuous dependence

3+1"



initial data: h - spatial metric
 K - extrinsic curvature

THANKS TO THEOREMS PROVED IN THE 1970S BY GERCH, CHOQUET-BRUHAT, AND OTHERS, WE KNOW INTIMATE LINKS

AMONG

GLOBAL HYPERBOLICITY \sim TIME FN \sim WELL-POSED CAUCHY PROBLEM

5. CHARACTERISTIC INITIAL VALUE PROBLEM

Sachs 1962, Penrose 1963, Dautcourt 1963, AND
OTHERS ... GEROCH, SMALLWOOD, D'INVERNO, STACHEL,
RENDALL, LUK ...

PHILOSOPHERS OF TIME HAVEN'T EXAMINED THIS CASE.
MY PRESENT INTEREST - CAN WE GET "PRODUCTION"
ARROW AND MT-ARROW TO MISALIGN?



NULL IVP : "INITIAL" DATA ON LIGHTLIKE SURFACE

- used in numerical relativity, holographic principle, in problems
concerned with radiation, quantum gravity, and elsewhere

ANSWER: YES!

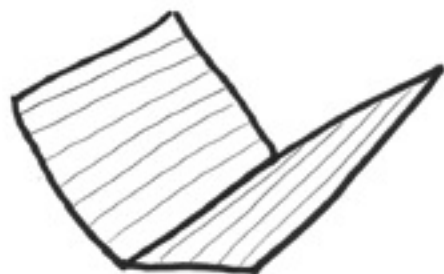
7. CHARACTERISTIC, CONT.



light cone



null-timelike



2+2



Asym null

"2+2" IS PERHAPS MOST POPULAR, MOST RESULTS ...

INTUITIVELY, THE MISALIGNED ARROWS ...



$A \rightarrow B$ "takes time"
 e.g. think flashlight turning on
 at A "produces" B

But well-posed problem
 tells us wedge 1
 produces wedge 2

6.

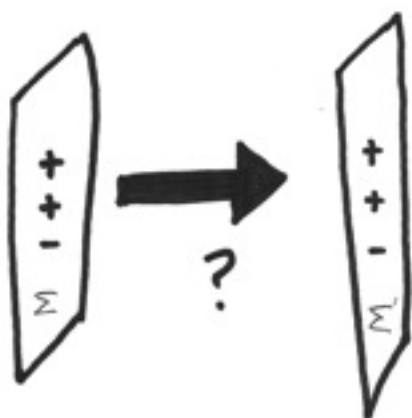
IS NULL-LIKE CASE AN UNNATURAL GAYESOME TWISTING OF SPACE-LIKE CASE?

- LOTS OF WELL-POSED PROBLEMS
- INITIAL DATA \sim GEOMETRICAL INVARIANTS W/ NATURAL INTERPRETATION
- CAN BE SET IN SPACETIMES WHERE SPACE-LIKE CASE CAN'T BE
- CLOSER TO COSMOLOGICAL PRACTICE (SOMEWHAT)
- BEST OF ALL, IN A WELL-DEFINED SENSE, MORE NATURAL BECAUSE NASTY INITIAL CONSTRAINTS GO AWAY (OR REDUCE TO ODE'S THAT ARE COMPARATIVELY EASY)

OF COURSE, PROBLEMS WITH CAUSTICS, ETC., BUT PROBLEMS, LIMITATIONS IN SPACELIKE CASE TOO.

9. TIMELIKE "INITIAL" VALUE PROBLEMS?

CAN WE GO EVEN FURTHER + PLACE DATA ON
MIXED (+ + -) 3-SURFACE + "EVOLVE" SIDEWAYS
INTO A SPACELIKE DIRECTION (+)?



THAT WOULD BE THE ULTIMATE MISALIGNMENT BETWEEN
PRODUCTION + TIME DIRECTIONS

SHORT ANSWER : **MAYBE** OPEN PROBLEM

No? Courant + Hilbert; Teismark ... If 2nd order linear PDE (lot of physics!)
then NO if data on (+ + -) surface

Yes? Craig + Weinstein: if constraints satisfied, then YES for free wave eq
Geroch conjecture: if constraints satisfied, then YES in KG + GR

10. CONCLUSION : WIN, WIN

IF NO ...

THEN WE LEARN AN IMPORTANT AND DEEP
DIFFERENCE BETWEEN TIME + SPACE, EVEN IN
RELATIVITY (RELATED TO METRIC SIGNATURE ASY)
TIME² IS THEN THE DIRECTION IN WHICH WE CAN
TELL THE MOST POWERFUL "STORIES"

+ OR TIME AND NULL ...

IF YES ...

THEN MESSY PICTURE OF PRODUCTION (IN SENSE HERE):



BUT TIME MIGHT STILL EMERGE AS BEST BALANCE
OF POWER + SIMPLICITY...