Codes:	BMA-LOTD-352.02, BMI-LOTD-352E.02, BMA-FILD-402.69, BBN-FIL-402.69
Course:	Branching spacetime and temporal logic
Teacher:	András Máté, Attila Molnár
Location and time:	I/224, Wed 13:00-14:30
Consultation:	Wed, 14:30 – 16:00, molnar.h.attila@gmail.com, phil.elte.hu/attila
First occasion:	09/09/2013, 12:00 – 14:00

Courses required:	Logic seminar and lecture
Requirements:	One of the following three options: Homeworks, oral exam or participation at a workshop at the end of the course (in the exam period). (The workshop participants present articles or own research. To ensure the success of this, regular consultation will be mandatory. The articles can be chosen from the papers suggested for further readings.)

Description: Basic temporal logics are modal logics with two modalities:

$\mathbf{F}\varphi$: "It will at some time be the case that φ", and
$\mathbf{P}\varphi$: "It has at some time been the case that φ".

In models of temporal logics, worlds are *moments*, and the alternative relation is a *linear ordering* of the moments. Such a line-like model is often called a "flow of time". Because of linearity, truth values of statements like

There will be a see battle tomorrow.

are already settled. To make a temporal logic which makes *indeterminism* possible, we should consider more general structures, for example trees. In a tree, the different branches would represent the alternative continuations of the present – on some of them there will be a see battle, but on the others, there won't be.

But even this picture is problematic. More than a hundred years ago we learned that time and simultaneity is relative to the observers. It can happen that Alice is sure about (=she measured) that two events are simultaneous but Bob has a different opinion (=measurement). This basically follows from the fact that the speed of light is the same for each observer – and this statement can be taken as the main axiom of the *special theory of relativity*.[a]

So if we want to fit temporal logics to the relativity phenomena, we should relativize it to observers; Alice's flow of time, Bob's flow of time, etc. But this looks absurd: Even if Alice and Bob disagree in which event happened earlier, the universe should have an opinion as well. The disagreement, which is an *epistemic* issue, should not effect the *ontological* status of events. Is there any place for an objective indeterminism in special relativity?

If we look into the books of physicists, we would find that spacetime models are all deterministic: There are no alternative possibilities, *branching spacetimes* in standard Physics.

Our goal is to give an introduction to indeterministic, or in other words, *branching* spacetimes with an emphasis on modalities.

Plan:

the numbers refers to the bibliography items (the first list of papers).

1. Basic temporal logic. [3]
2. Special Relativity. [1]
3. Modal logic of Minkowski space-times. [4]
4. Indeterminist (Newtonian space-)time. [5]
5. Indeterminist special relativistic space-time. [2]
6. Glimpses beyond: Indeterminism in general relativity.

[a] This axiom is under constant confirmation by our GPS systems. If we calibrate our GPS systems back to Newtonian physics (where simultaneity and time is absolute), then the approximated error would be 10 km/day.

Bibliography:

[1] H. Andréka, J. X. Madarász, and I. Németi. "Logic of space-time and relativity theory". In: *Handbook of spatial logics*. Ed. by M. Aiello, I. Pratt-Hartmann, and J. van Benthem. Dordrecht: Springer-Verlag, 2007, pp. 607–711.

[2] Nuel Belnap. "Branching Space-Time". In: *Synthese* 92.3 (1992), pp. 385–434.

[3] P. Blackburn, M. de Rijke, and Y. Venema. *Modal Logic*. Cambridge: Cambridge University Press, 2001. ISBN: 0521527147, 9780521527149.

[4] Robert Goldblatt. "Diodorean Modality in Minkowski Spacetime". In: *Studia Logica* 39.2-3 (1980), pp. 219–236.

[5] Richmond H. Thomason. "Indeterminist Time and Truth-Value Gaps". In: *Theoria* 36.3 (1970), pp. 264–281.

Further readings:

[1] Ferenc Altrichter. *Észérvek az európai filozófiai hagyományban*. Budapest: Atlantisz, 1993, pp. 289–327. ISBN: 963-79-7835-6.

[2] H. Andréka et al. "A logic road from special relativity to general relativity". In: *Synthese* 186.3 (2012), pp. 633–649. ISSN: 0039-7857. URL: http://dx.doi.org/10.1007/s11229-011-9914-8.

[3] H. Andréka et al. "Axiomatizing relativistic dynamics without conservation postulates". In: *Studia Logica* 89.2 (2008), pp. 163–186. ISSN: 0039-3215.

[4] Nuel Belnap. "Newtonian Determinism to Branching Space-Times Indeterminism in Two Moves". In: *Synthese* 188.1 (2012), pp. 5–21.

[5] Nuel Belnap and Mitchell Green. "Indeterminism and the Thin Red Line". In: *Philosophical Perspectives* 8 (1994), pp. 365–388.

[6] H. Ben-Yami. "Causality and temporal order in special relativity". In: *British J. Philos. Sci.* 57.3 (2006), pp. 459–479. ISSN: 0007-0882.

[7] P. Blackburn, M. de Rijke, and Y. Venema. *Modal Logic*. Cambridge: Cambridge University Press, 2001. ISBN: 0521527147, 9780521527149.

[8] J. X. Madarász and G. Székely. "Comparing Relativistic And Newtonian Dynamics In First Order Logic". In: *Wiener Kreis und Ungarn*. Ed. by F. Stadler. To appear. Veröffentlishungen des Instituts Wiener Kreis, Vienna, 2009.

[9] T. Müller. "Introduction: The Many Branches of Belnap's Logic". In: *Nuel Belnap on Indeterminism and Free Action*. Ed. by T. Müller. Springer, 2014.

[10] Michael Perloff and Nuel Belnap. "Future Contingents and the Battle Tomorrow". In: *Review of Metaphysics* 64.3 (2011), pp. 581–602.

[11] T. Placek. "Branching for General Relativists". In: *Nuel Belnap on Indeterminism and Free Action*. Ed. by T. Müller. Springer, 2014.

[12] T. Placek and T. Müller. "Branching Space-Times". In: *Studies in History and Philosophy of Science Part B* 38.3 (2007), pp. 590–592.

[13] Tomasz Placek. "A Locus for "Now"". 2010.

[14] Tomasz Placek. "On Individuals in Branching Histories". In: *Synthese* 188.1 (2012), pp. 23–39.

[15] Tomasz Placek. "Possibilities Without Possible Worlds/Histories". In: *Journal of Philosophical Logic* 40.6 (2011), pp. 737–765.

[16] Imre Ruzsa. *Logikai szintaxis és szemantika*. Budapest: Akadémiai Kiadó, 1988. ISBN: 963-05-5313-9.

[17] László E. Szabó. *A nyitott jövő problémája*. Budapest: Typotex, 2002.