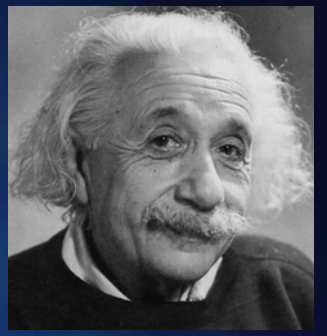

IS TIME A REAL TIME?

TIME ONTOLOGY AND INFORMATICS

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PRESENTATION SUMMARY

- THE NATURE OF TIME
  - IN PHILOSOPHY
  - IN PHYSICS
- TIME MATERIALISATION
  - ELECTRONIC ENGINEERING
  - COMPUTER ENGINEERING
- TIME REPRESENTATION
  - IN COMPUTER ENGINEERING
  - IN INFORMATION SYSTEMS

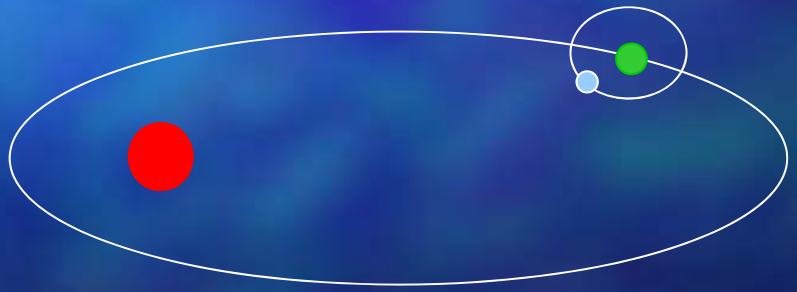
?

$\Box[Gp \supset p] \supset [Gp \supset Hp]$

$\Box[(\Box r \wedge \Diamond t) \rightarrow \Diamond t]$

THE NATURE OF TIME IN ANCIENT CIVILISATIONS (1)

- TIME IS RELATED TO NATURAL PHENOMENA
  - CYCLIC PROCESSES REPETITION
  - EXCEPTIONS CREATE SUPERSTITION



THE NATURE OF TIME IN ANCIENT CIVILISATIONS (2)

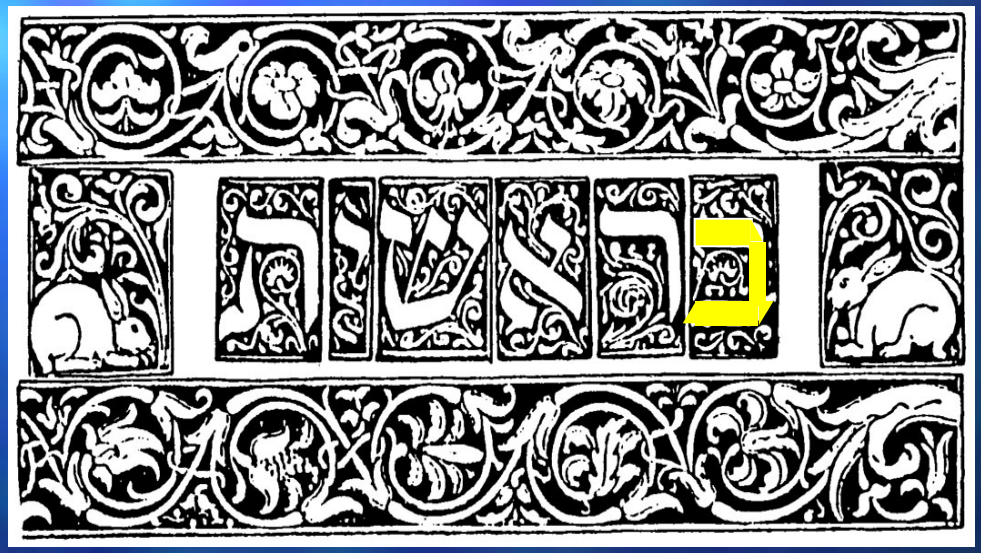
- TIME HAS A PRACTICAL VALUE TO HUMAN ACTIVITIES
- TIME MEASUREMENT IS IMPORTANT
  - DEVELOPMENT OF ASTRONOMY (ASSIRO-BABILONIANS, MAYA)
  - COLLECTION AND DIFFUSION OF TEMPORAL INFORMATION IS A PRIESTLY TASK

THE NATURE OF TIME IN ANCIENT CIVILISATIONS (3)

- IN PERSIA, ZOROASTRIANS DEVELOP AN OPEN CONCEPTION OF THE TIME STRUCTURE

THE NATURE OF TIME IN ANCIENT CIVILISATIONS (4)

- JEWS CONSIDER AN **OPEN AND LINEAR** STRUCTURE



PHILOSOPHYCAL THEORIES (1)

- TIME AND SPACE ARE PERCEIVED AS DIFFERENT FROM OTHER THINGS AND PROCESSES
  - CONTAINERS OF NATURAL EVENTS (ABSOLUTISTS)
  - ABSTRACTIONS REPRESENTING RELATIONSHIPS AMONG OBJECTS AND PROCESSES (RELATIVISTS)

PHILOSOPHYCAL THEORIES (2)

- SPACE IS GIVEN MORE IMPORTANCE THAN TIME
  - THE ELEATIC SCHOOL (PARMENIDES, ZENO,...) CONSIDERS TIME A DISTURBANCE OF AN IMMUTABLE BEING
  - ERACLITUS AND THE STOIC SCHOOL CONSIDER THE BECOMING AS A SERIES OF BIRTH AND DEATH TRANSMUTATION CYCLES OF AN IMMUTABLE SUBSTANCE

PHILOSOPHYCAL THEORIES (3)

- FOR PLATO TIME IS THE PRODUCT OF THE CELESTIAL SPHERE REVOLUTION, SINCE IT HAS BEEN CREATED WITH IT

PHILOSOPHYCAL THEORIES (4)

- ARISTOTLE WAS THE FIRST WHO GAVE TIME AN AUTONOMOUS DIGNITY
  - TIME IS THE NUMERABLE ASPECT OF MOTION
  - TIME INTRODUCES THE FIRST → AFTER ORDERING
  - THE CIRCULAR UNIFORM MOTION IS USED TO MEASURE TIME
  - THE PRESENT TIME SEPARATES PAST AND FUTURE
  - INFINITY AND CONTINUITY IMPLY CIRCULARITY
  - IS TIME A SUBJECTIVE FEELING?

PHILOSOPHYCAL THEORIES (5)

- THE ATOMISTIC SCHOOL (DEMOCRITUS, EPICURUS, ...) ABANDONS THE CYCLIC VIEW
  - TIME IS OPEN AT LEFT (NOT CREATED) AND CLOSED AT RIGHT (EVOLUTION IS BUT A STATE TRANSFORMATION)
- STOICS AND MEGARIANS INTRODUCE TIME MODALITIES

PHILOSOPHYCAL THEORIES (6)

- S. AUGUSTIN DISCOVERS TIME AS A PHILOSOPHYCAL PROBLEM AGAIN
  - TIME HAS A LINEAR STRUCTURE
  - TIME IS A SUBJECTIVE PERCEPTION
    - ONLY PRESENT IS REAL
    - PAST LIES IN MEMORY
    - FUTURE IS IN EXPECTATION

PHILOSOPHYCAL THEORIES (7)

- KANT LOOKS AT SPACE AND TIME AS THE TWO MODALITIES OF INTUITION WHICH ALLOW TO FORMULATE THE APRIORI SYNTHETIC JUDGMENTS

- AFTER KANT, SPACE AND TIME BECOME SCIENTIFIC OBJECTS ON THEIR OWN, TO BE STUDIED IN THE DOMAIN OF PHYSICS

THE MAIN PHILOSOPHICAL ISSUES

- LINEAR vs. CIRCULAR
- FINITE vs. INFINITE
- OPEN vs. CLOSED
- DISCRETE vs. CONTINUOUS
- ORDERING
  - ABSOLUTE {past, present, future}
  - RELATIVE {before, concurrent with, after}
- OBJECTIVE vs. SUBJECTIVE
- TEMPORAL MODALITIES

PHYSICAL THEORIES (1)

THE BIRTH OF MECHANICS

- TIME IS THE **PRIVILEGED INDIPENDENT VARIABLE** FOR OBSERVING AND DESCRIBING MOTION AND TO FORMULATE PHYSICAL LAWS

PHYSICAL THEORIES (2)

- NEWTON
  - TIME IS AN ABSOLUTE MATHEMATICAL ENTITY
- LEIBNITZ
  - TIME IS A RELATIVE ORDERING RELATION

PHYSICAL THEORIES (3)

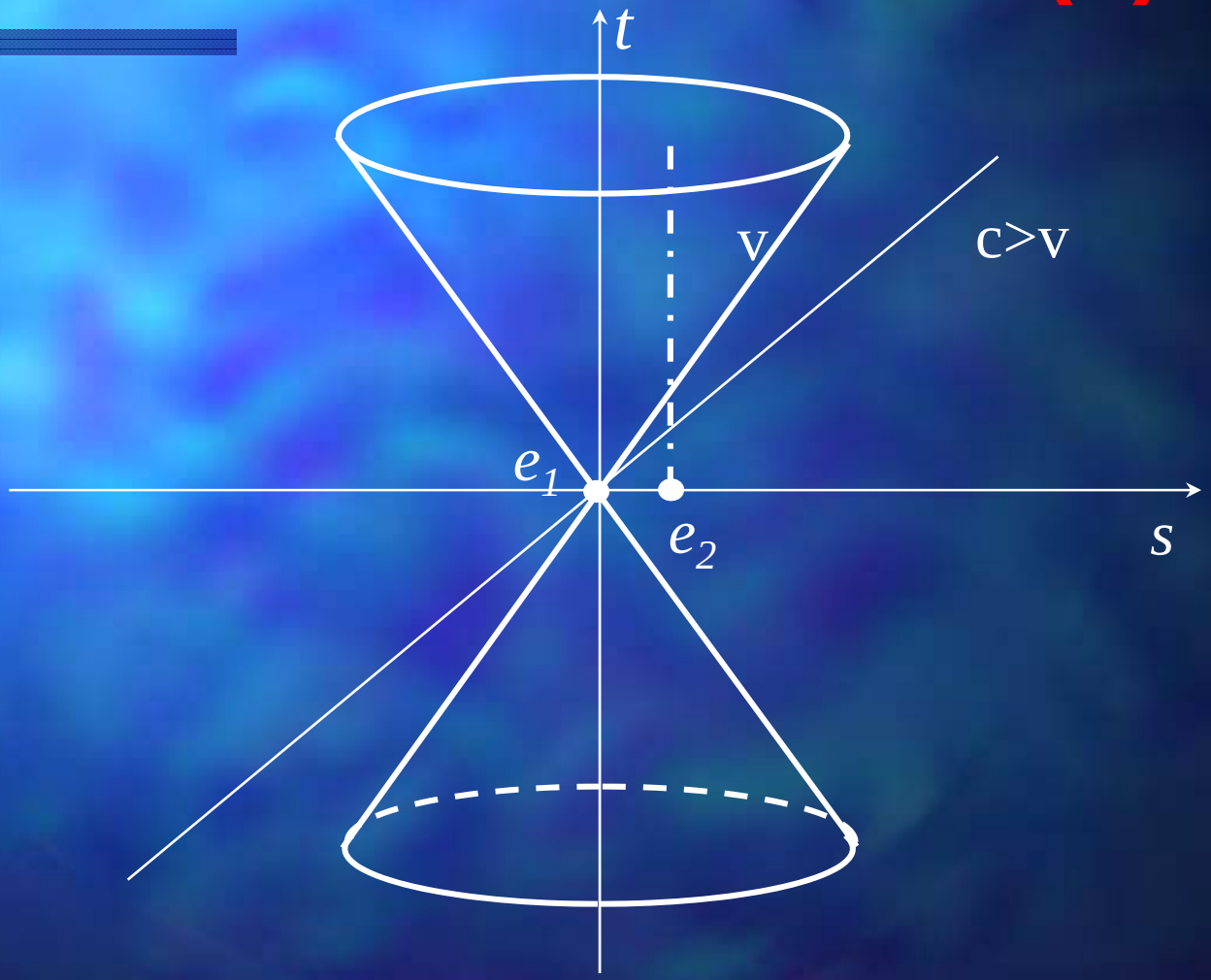
- **EINSTEIN**
  - TIME IS BUT A LOCAL VARIABLE
  - CLOCK READINGS CAN ONLY BE COMPARED BY INFORMATION EXCHANGE
  - INFORMATION CANNOT TRAVEL FASTER THAN LIGHT (RELATIVITY OF SIMULTANEITY)

PHYSICAL THEORIES (4)

RELATIVITY THEORY CONSEQUENCES

- THERE EXISTS A SINGLE FOUR DIMENSIONS SPACE-TIME CONTINUUM
- CAUSALITY RELATIONSHIPS CAN EXIST ONLY INSIDE THE LIGHT CONE

PHYSICAL THEORIES (5)



OTHER PHYSICAL ISSUES (1)

- IS BECOMING REAL?
  - EXISTENCE OF A TIME ARROW
  - EXISTENCE OF IRREVERSIBLE PHENOMENA (PRIGOGINE)

OTHER PHYSICAL ISSUES (2)

- WE DO NOT HAVE A CONSISTENT DESCRIPTION OF TIME BETWEEN MACROCOSM AND MICROCOSM
  - GENERAL RELATIVITY THEORY
  - QUANTUM THEORY

BUT THEN, IS TIME REAL?

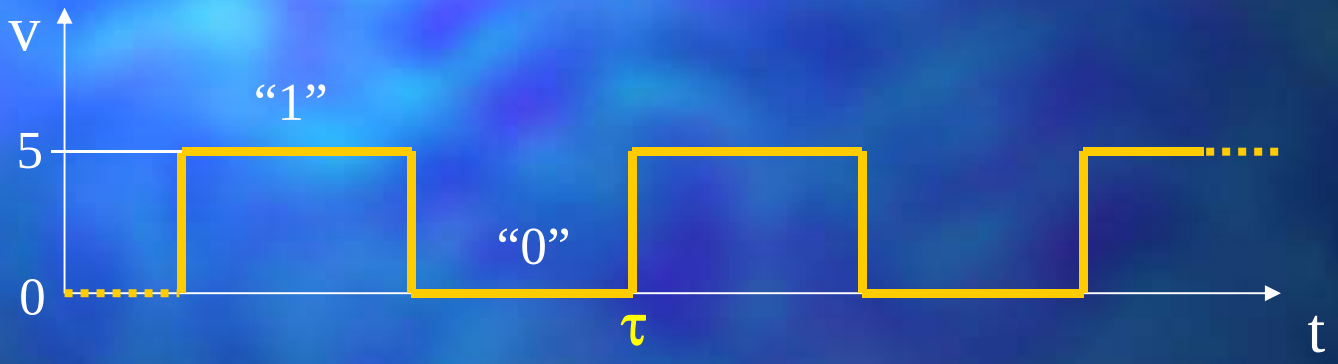
TIME MATERIALISATION IN COMPUTING SYSTEMS

THE CLOCK IS THE CORE OF EVERY DIGITAL SYSTEM

- CLOCK GENERATION
- CLOCK DISTRIBUTION
- CLOCKS SYNCHRONISATION

CLOCK GENERATION (1)

CLOCK IS A **BINARY SIGNAL**
CONSTITUTED BY A SQUARE WAVE

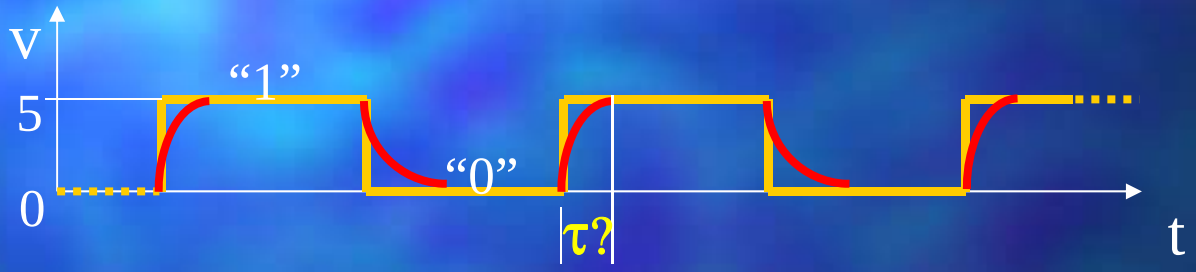


RISING (FALLING) **EDGES** DETERMINE THE **INSTANTS** (TICK)

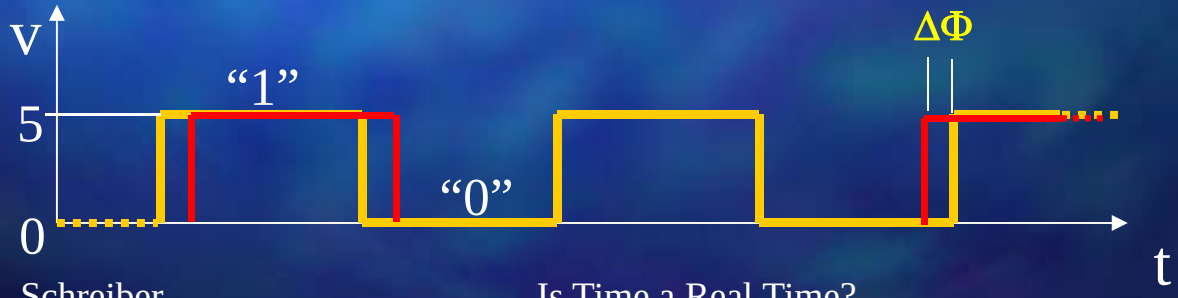
CLOCK GENERATION (2)

CLOCK IS AFFECTED BY ERRORS AND IMPRECISIONS

- FINITE TRANSITION TIME



- PHASE VIBRATION (JITTER)



CLOCK GENERATION (3)

GENERAL CLOCK EQUATION

$$x(t) = p(((f + \Delta f)t + \Phi(t)) \bmod 1$$

INSTANTANEOUS FREQUENCY

$$f(t) = f + \Delta f + d\Phi(t)/dt$$

- IF $(f + \Delta f) = constant$ → **ISOCHRONOUS**
- IF $\Delta f = \Delta f(t)$ → **ANISOCHRONOUS**

CLOCK GENERATION (4)

FREQUENCY STABILITY

- H_2 MASER → $2*10^{-14}/d \pm 1*10^{-12}/y$
- QUARTZ → $10^{-6}/d$

DISTRIBUTED SYSTEMS SYNCHRONISATION (1)

- MESSAGE TRANSMISSION DELAY NOT NEGLIGIBLE W.R.T. THE TIME BETWEEN TWO EVENTS IN A LOCAL SYSTEM
- MANY LOCAL CLOCKS EXIST WHICH ARE NEARLY ALIGNED (PLESIOCHRONOUS)

DISTRIBUTED SYSTEMS SYNCHRONISATION (2)

SYNCHRONISATION MAKES

- DIFFERENT PROCESSES IN A COMPUTER NETWORK
- DIFFERENT PARTS IN A CIRCUIT
- DIFFERENT CLOCKS

AGREE ON THE SAME TIME READING

IMPORTANCE OF SYNCHRONISATION

IN CONCURRENT PROCESSING ENVIRONMENTS, IT GRANTS THE OPERATIONS LOGICAL ORDERING AND THE POSSIBILITY TO ESTABLISH CAUSE – EFFECT RELATIONSHIPS

- THE ***HAPPENED BEFORE*** RELATIONSHIP IS IMPLICIT IN WHATEVER SEQUENTIAL COMPUTATION
  - GLOBAL CLOCK → TOTAL ORDERING OF EVENTS
  - LOCAL CLOCKS → ONLY PARTIAL ORDERINGS

CLOCK TYPES

- **LOGICAL CLOCK**
  - MONOTONIC NON DECREASING FUNCTION WHICH MAPS THE EVENTS ON THE INTEGERS SET (TIME STAMPS)
  - IT PROVIDES A RELATIVE TIME
- **PHYSICAL CLOCK**
  - PHYSICAL DEVICE PROVIDING AN ABSOLUTE TIME

A SET OF GOOD PHYSICAL CLOCKS IS PLESIOCHRONOUS

SYNCHRONISATION PROTOCOLS

IN ANY CASE WE NEED SYNCHRONISATION PROTOCOLS WHICH BE ROBUST EVEN IN PRESENCE OF FAILURES

- IN THE PROCESSING NODES
- IN THE TRANSMISSION SYSTEM
- IN THE SYNCHRONISATION PROCEDURE ITSELF

BYZANTINE PROTOCOLS

SYNCHRONISATION ONTOLOGICAL ISSUES

- PHYSICAL CLOCKS ARE CONTINUOUS
- LOGICAL CLOCKS ARE DISCRETE
- RELATIVE TIME IS ENOUGH FOR PROCESS SYNCHRONISATION IN ISOLATED SYSTEMS
- ABSOLUTE TIME IS MANDATORY FOR ESTABLISHING CAUSAL RELATIONSHIPS IN OPEN SYSTEMS

TIME REPRESENTATION (LOGIC AGAIN!)

NATURAL LANGUAGE THEORIES

- TENSER (VERBAL TENSES ARE FUNDAMENTAL COMPONENTS OF LANGUAGES)
  - PAST – PRESENT – FUTURE
  - MODAL LOGIC APPROACH
  - SUPPORTED BY LINGUISTS
- DETENSER (VERBAL TENSES CAN BE DERIVED)
  - BEFORE – SIMULTANEOUS WITH – AFTER
  - FIRST ORDER LOGIC APPROACH
  - SUPPORTED BY MATEMATICIANS AND PHYSICISTS

FIRST ORDER LOGIC CAN BE SEEN AS AN INTERPRETATION OF THE MODAL APPROACH

TIME REPRESENTATION

APPLICATIONS TO KNOWLEDGE THEORY

… TEMPORAL LOGIC IS USED TO ENABLE COMPUTER PROGRAMS TO REASON ABOUT THE WORLD …

APPLICATIONS TO SOFTWARE ENGINEERING

… TEMPORAL LOGIC IS USED TO ENABLE THE WORLD TO REASON ABOUT COMPUTER PROGRAMS

(Galton)

ONTOLOGICAL ISSUES ABOUT REPRESENTATION

- PRIMITIVE TIME ENTITIES
- TEMPORAL RELATIONSHIPS
- BOUNDEDNESS
- TIME TOPOLOGY
- TIME STRUCTURE
- TEMPORAL METRICS

PRIMITIVE TIME ENTITIES

- **INSTANTS** (POINTS IN TIME)
- **INTERVALS** (SEGMENTS OF TIME)
- **EVENTS** (OCCURRENCIES IN TIME)

- **ABSOLUTISTIC** VIEW
  - TIME ONTOLOGICALLY PRECEDES EVENTS
- **RELATIVISTIC VIEW**
  - EVENTS ONTOLOGICALLY PRECEDE TIME

SINCE EVENTS ARE SPATIO-TEMPORAL ENTITIES THEIR CHOICE AS TEMPORAL PRIMITIVES IS QUESTIONABLE

TEMPORAL RELATIONSHIPS

- INSTANTS → PRECEDENCE RELATION
- INTERVALS → 13 RELATIONS (ALLEN)

before (x y)

meet (x y)

overlap (x y)

during (x y)

start (x y)

finishes (x y)

equal (x y)

AND THEIR 6 SIMMETRIC

BOUNDEDNESS

DOES IT ESIST A FIRST (LAST) MOMENT IN TIME?

- NO BEGINNING AND NO ENDING TIMES
  - → HOMOGENEOUS TIME STRUCTURE
- INTERVALS ARE OPEN (CLOSED) AT ONE OR BOTH ENDS
  - → THE DIVIDING INSTANT PROBLEM FOR VARIABLES CHANGING THEIR VALUE BETWEEN TWO CONSECUTIVE INTERVALS
    - ESCLUDED THIRD PRINCIPLE (p and $\neg p$ non simultaneously *FALSE*)
    - NON CONTRADICTION PRINCIPLE (p and $\neg p$ non simultaneously *TRUE*)

TIME TOPOLOGY

A TRAJECTORY IN TIME IS EQUIVALENT TO AN ORDER RELATION (before → after)

- TOTAL (NATURAL SCIENCES)
  - LINEAR
  - PERIODIC
- PARTIAL (COMPUTER SCIENCE)
  - BRANCHING IN THE PAST (police investigation)
  - BRANCHING IN THE FUTURE (business planning)

  PHILOSOPHERS ARGUE WETHER TO CONSIDER BRANCHING OF TIME OR IN TIME

TIME STRUCTURE

- CONTINUOUS → $\mathcal{R}$ (reals)
- DENSE → $\mathcal{Q}$ (rationals)
- DISCRETE → $\mathcal{Z}$ (integers)

- $\mathcal{Q}$ AND $\mathcal{Z}$ → NO PROBLEM AS TO THE DIVIDING INSTANT
- $\mathcal{R}$ AND $\mathcal{Q}$ → RULE OUT FINITENESS

TEMPORAL METRICS (1)

ALLOW THE TRANSITION FROM QUALITATIVE TEMPORAL SYSTEMS TO CHRONOLOGICAL SYSTEMS

- **DISTANCE FUNCTION**
  - NULL DISTANCE $d(t,t')=0$ *iff* $t=t'$
  - TRIANGULAR INEQUALITY $d(t,t')+d(t',t'') \geq d(t'',t')$
- **REFERENCE ELEMENT**
  - **0** IS INTERPRETED AS THE **PRESENT**

TEMPORAL METRICS (2)

- LINEAR ORDERING
- WITH BRANCHING TIME STRUCTURES METRIC NOTIONS BECOME TRICKY
  - SIMULTANEITY DEFINITION IN DIFFERENT BRANCHES
  - COMPARABILITY OF CLOCKS IN DIFFERENT BRANCHES

TEMPORAL METRICS (3)

METRIC UNITS → GRANULARITY

- CRONOLOGICALLY STABLE DATES (october 18th, 2010)
- CRONOLOGICALLY UNSTABLE PSEUDO-DATES (yesterday, tomorrow)
- PERIODICITY

REASONIONG AND PLANNING APPLICATIONS

- ACTIVITY PLANNING
- DECISION SUPPORT SISTEMS
- FAULT DIAGNOSIS
- OFFICE SYSTEMS
- DEDUCTIVE AND TEMPORAL DATA BASES

TEMPORAL REASONING SYSTEMS (1)

MOSTLY BASED ON ALLEN'S TEMPORAL INTERVALS

- OBJECTS PROPERTIES HOLD IN EVERY SUBINTERVAL
- EVENTS DEFINE THE INTERVAL IN WHICH THEY OCCUR
- PROCESSES OCCOUR DURING SOME SUBINTERVAL

MOST AUTHORS PREFER FIRST ORDER CALCULUS AGAINST MODAL LOGIC

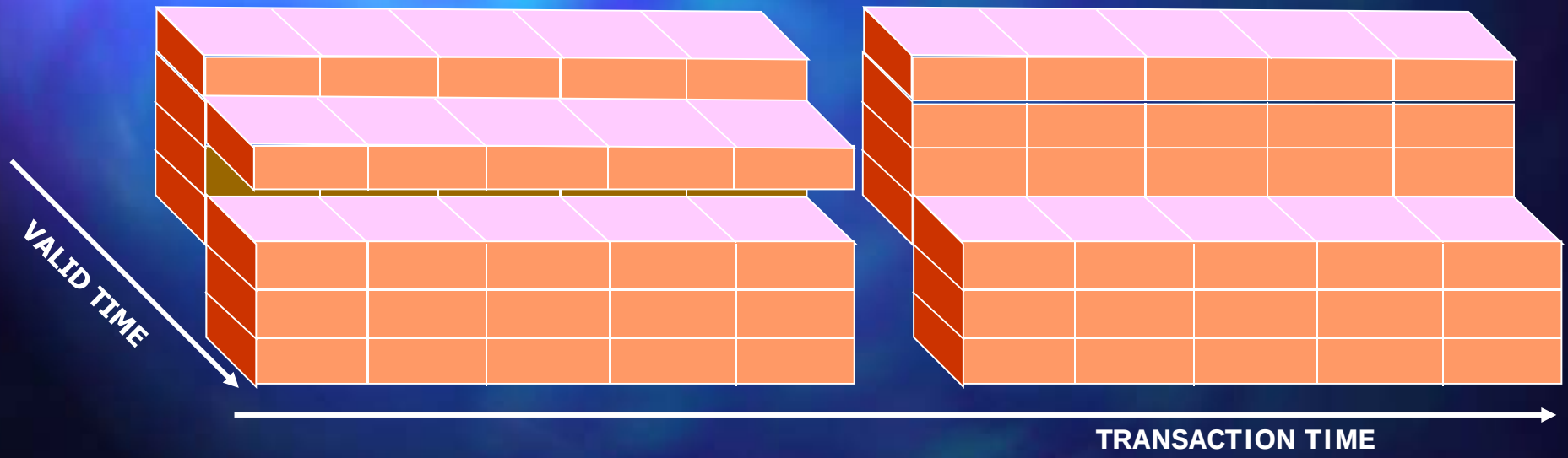
TEMPORAL REASONING SYSTEMS (2)

Author	Allen[All1]	McDerm.[Mcd1]	TSOS[MPB1]	EC[KSe1]	TMM[DMD1]
Time Primitive	interval	point	point	event	point
Time Reference	relative	relative	abs/rel	relative	relative
Time Topology	linear	R-branch.	linear	linear	R-branch.
Time Bounds	[–)	∞	[–) ; ∞	(–)	[→∞
Time Structure	continuous	continuous	discrete	discrete	discrete
Time Metric	no	no	yes	no	yes

[–) means left-closed, right-open interval

TEMPORAL DATA BASES (1)

- TDBs KEEP THE COMPLETE HISTORY OF UPDATES
- THEY ALLOW COMPLEX FORMS OF TEMPORAL TRANSACTIONS



TEMPORAL DATA BASES (2)

- SNAPSHOT
  - CONVENTIONAL DATA BASES
- ROLLBACK
  - ALL PAST SNAPSHOT TIME-STAMPED BY THEIR TRANSACTION TIME
- HISTORICAL
  - ONLY VALID TUPLES TIME-STAMPED BY THEIR VALID TIME
- TEMPORAL
  - THE COMPLETE DB HISTORY

TEMPORAL DATA BASES (3)

COMPARISON BETWEEN LINGUISTICS AND TEMPORAL DBs

REICHENBACH		SNODGRASS
UTTERANCE TIME	→	QUERY TIME
EVENT TIME	→	VALID TIME
REFERENCE TIME	→	TRANSACTION TIME

Yesterday Svetonius said — TP/TI
that Cesar arrived to Rome
one month after his Rubicone crossing — TR/TT
and there he stayed for the rest of his days — TE/TV

SOFTWARE ENGINEERING APPLICATIONS (1)

- SEQUENTIAL PROGRAMMING HAS NO SPECIAL TIMING PROBLEMS
- CONCURRENT PROGRAMMING NEEDS TIMING ANALYSIS
  - PROPOSITIONAL LOGIC AND FIRST ORDER CALCULUS ARE USED FOR STATIC ANALYSIS
  - MODAL LOGIC IS USED FOR DYNAMIC ASPECTS
- REACTIVE SYSTEMS (R-T and O.S.)
  - INTERACT WITH THE ENVIRONMENT
  - DO NOT TERMINATE

SOFTWARE ENGINEERING APPLICATIONS (2)

REACTIVE SYSTEMS PROPERTIES

- **SAFETY** (INVARIANCE) → nothing bad will happen
  - EXPRESSED THROUGH THE *ALWAYS* (NECESSITY) MODAL CLAUSE $\Box p$
    - PARTIAL CORRECTNESS
    - FREEDOM FROM DEADLOCKS
- **LIVENESS** (EVENTUALITY) → something good will happen
  - EXPRESSED THROUGH THE *SOMETIMES* (POSSIBILITY) MODAL CLAUSE $\Diamond p$
    - TOTAL CORRECTNESS
    - RESPONSIVITY
- **FAIRNESS** (PRECEDENCE) → some event always precedes another one
  - EXPRESSED THROUGH THE *UNTIL* MODAL CLAUSE Up
    - ABSENCE OF UNSOLICITED RESPONSES
    - FAIR RESPONSIVENESS

SOFTWARE ENGINEERING APPLICATIONS (3)

- **MODAL** LOGIC IS PREFERRED TO STANDARD LOGIC
- **DISCRETE** TIME MODELS
- **INSTANTS** OR **EVENTS** ASSUMED AS FUNDAMENTAL ENTITIES
- A TEMPORAL LOGIC WITH THE ***UNTIL*** OPERATOR AND RESTRICTED TO THE **FUTURE FRAGMENT** IS SUFFICIENT TO EXPRESS ALL THE FIRST ORDER PROPERTIES OF REACTIVE SYSTEMS

SOFTWARE ENGINEERING APPLICATIONS (4)

- VERIFICATION SYSTEMS
  - PROPOSITIONAL CALCULUS
  - LINEAR OR BRANCHING TOPOLOGIES
  - NO METRIC
- R-T SPECIFICATION LANGUAGES
  - 1ST ORDER PREDICATE CALCULUS
  - LINEAR TOPOLOGY
  - METRIC

VERIFICATION SYSTEMS

Author	Lamport [Lam2]	Ben Ari [BPM1]	Manna [MPn1]	Emerson [EHa1]
Scope	conc. ver.	conc. ver.	conc. ver.	conc. ver.
Approach	modal propos.	modal propos.	modal propos.	modal propos.
Primitive	point	point	point	point
Reference	–	–	–	–
Topology	linear	branch/circ	linear	branching
Direction	future	future	future	future
Bounds	$[\rightarrow \infty$	∞	$[\rightarrow \infty$	$[\rightarrow \infty$
Structure	discrete	discrete	discrete	discrete
Metric	no	no	no	no

$[\rightarrow$ means left-closed, right-open interval

R-T SPECIFICATION LANGUAGES

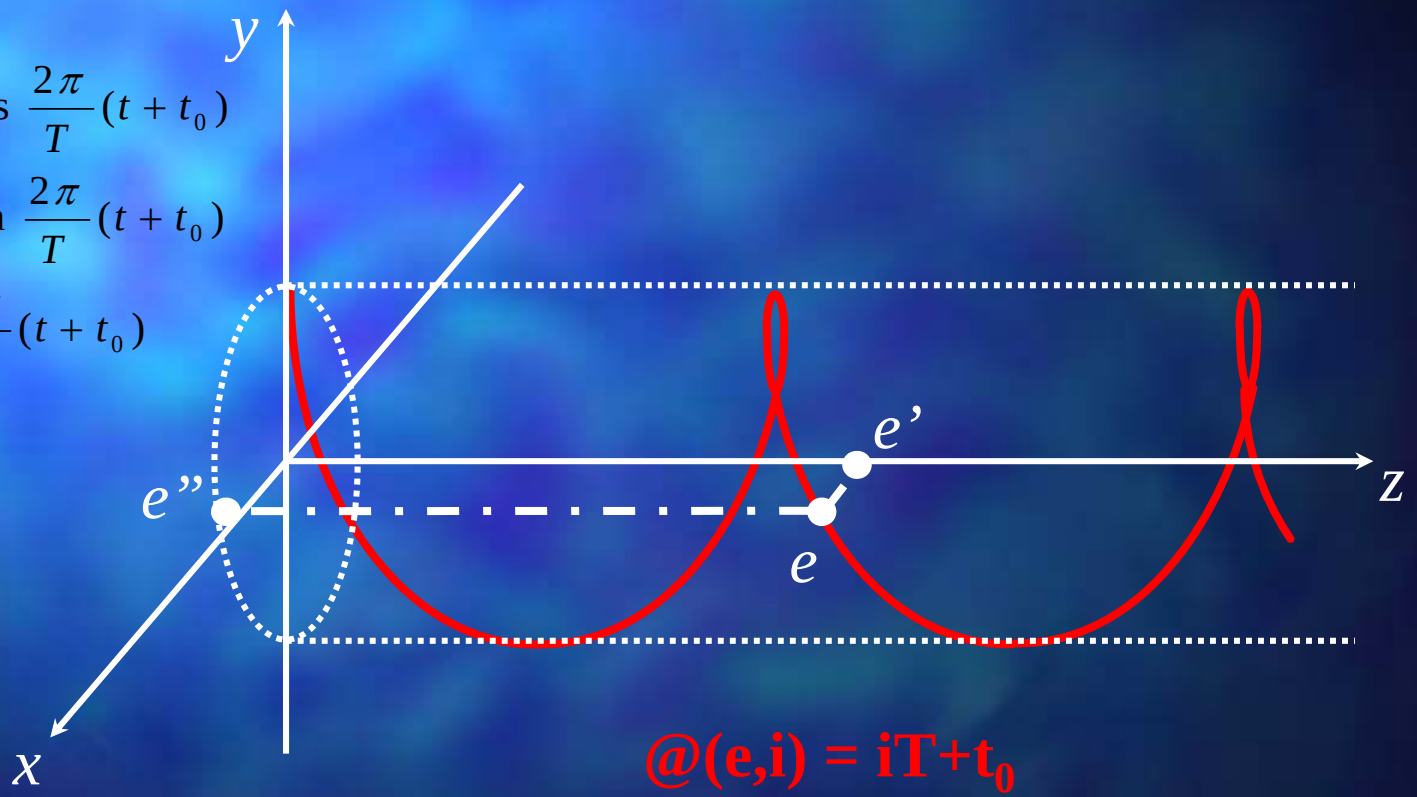
Author	Koymans [Koy1]	RTL [JMo1]	ITL [Mos1]	TRIO [FMM1]
Scope	RT spec./ver.	RT spec./ver./synth.	conc. spec./ver.	RT spec./ver.
Approach	modal 1*st* ord.	non modal 1*st* ord.	modal 1*st* ord.	modal 1*st* ord.
Primitive	point	event (point)	interval	point
Reference	relative	abs/rel	relative	relative
Topology	linear	helix	linear	linear
Direction	past/future	–	future	past/future
Bounds	∞	[→ ∞	[→ ∞	∞
Structure	continuous	discrete	discrete	cont./discr.
Metric	yes	yes	no	yes

[→ means left-closed, right-open interval

R-T SPECIFICATION LANGUAGES

TOPOLOGY OF THE @ FUNCTION IN RTL

$$\text{helix} \begin{cases} x = A\cos\dfrac{2\pi}{T}(t+t_0) \\ y = A\sin\dfrac{2\pi}{T}(t+t_0) \\ z = h\dfrac{2\pi}{T}(t+t_0) \end{cases}$$



@(e,i) = iT+t_0

FLABBY CLOCKS, THE PERSISTENCE OF MEMORY

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