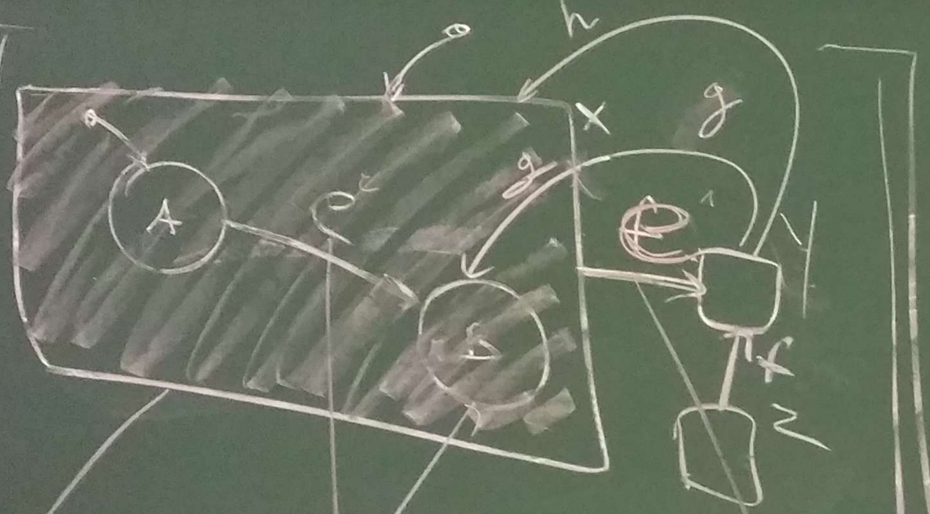
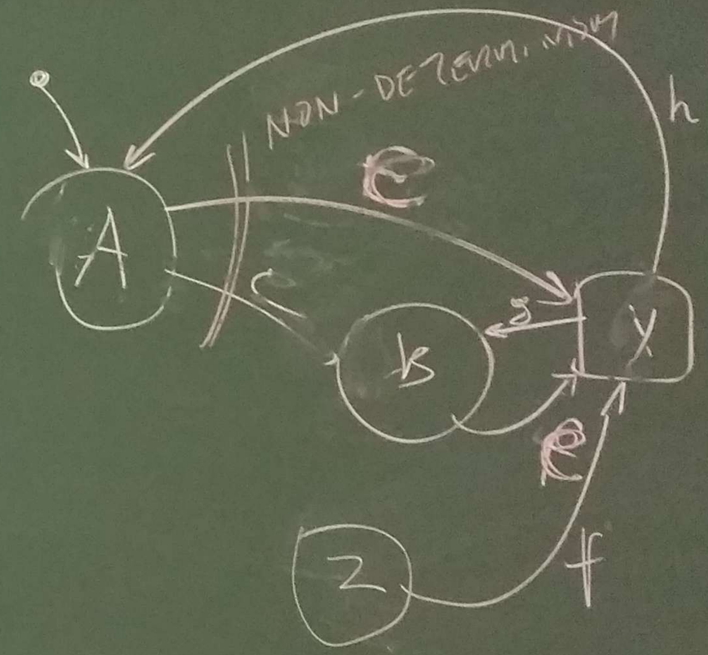
un stato = "A"

STATECHARTS = HiGRAPHS + FSA + TIME

HIERARCHY



=



COMPOSITE / SUPER STATE

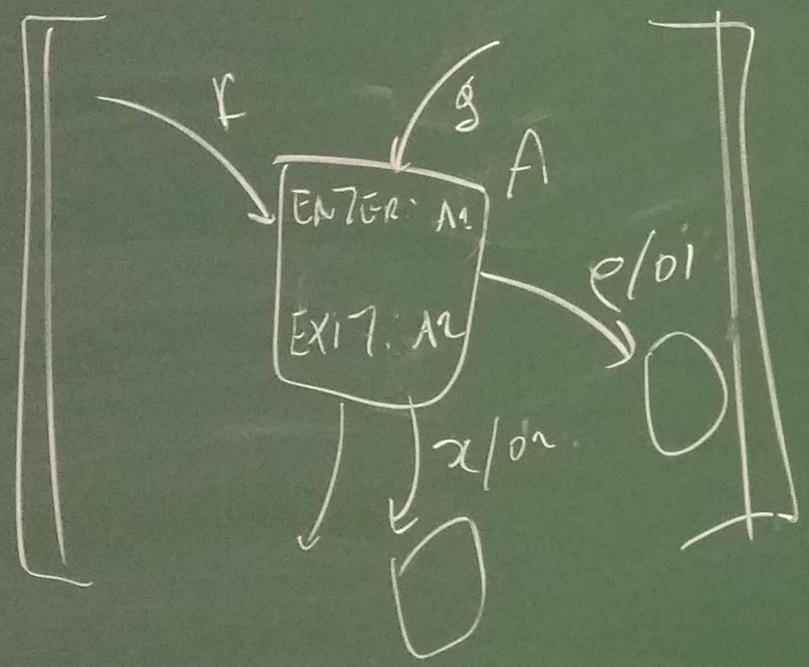
ATOMIC STATE
BASIC

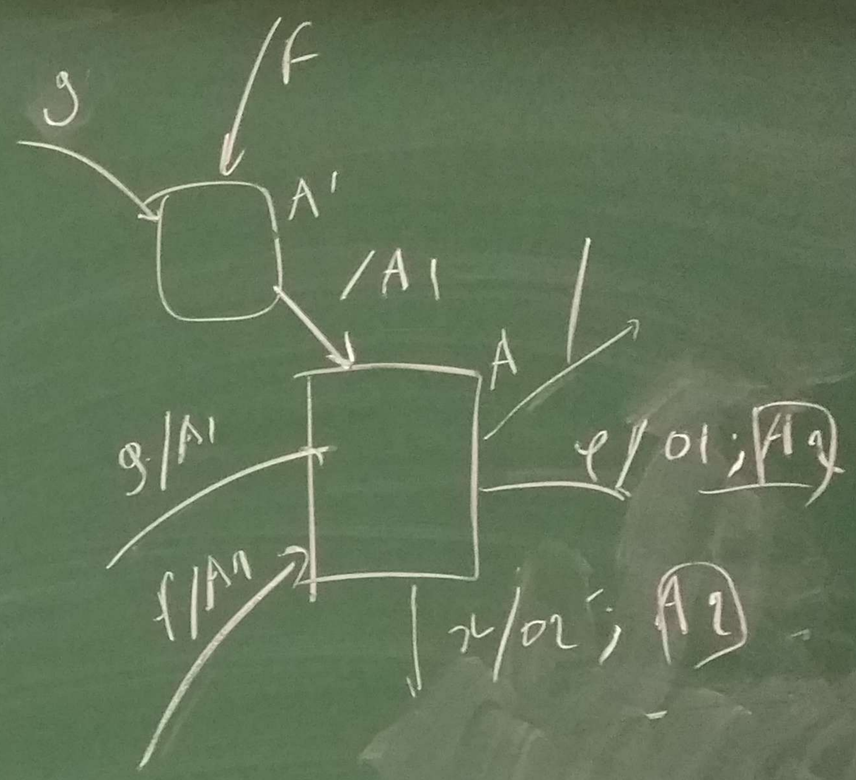
INNER
UML
HAREL

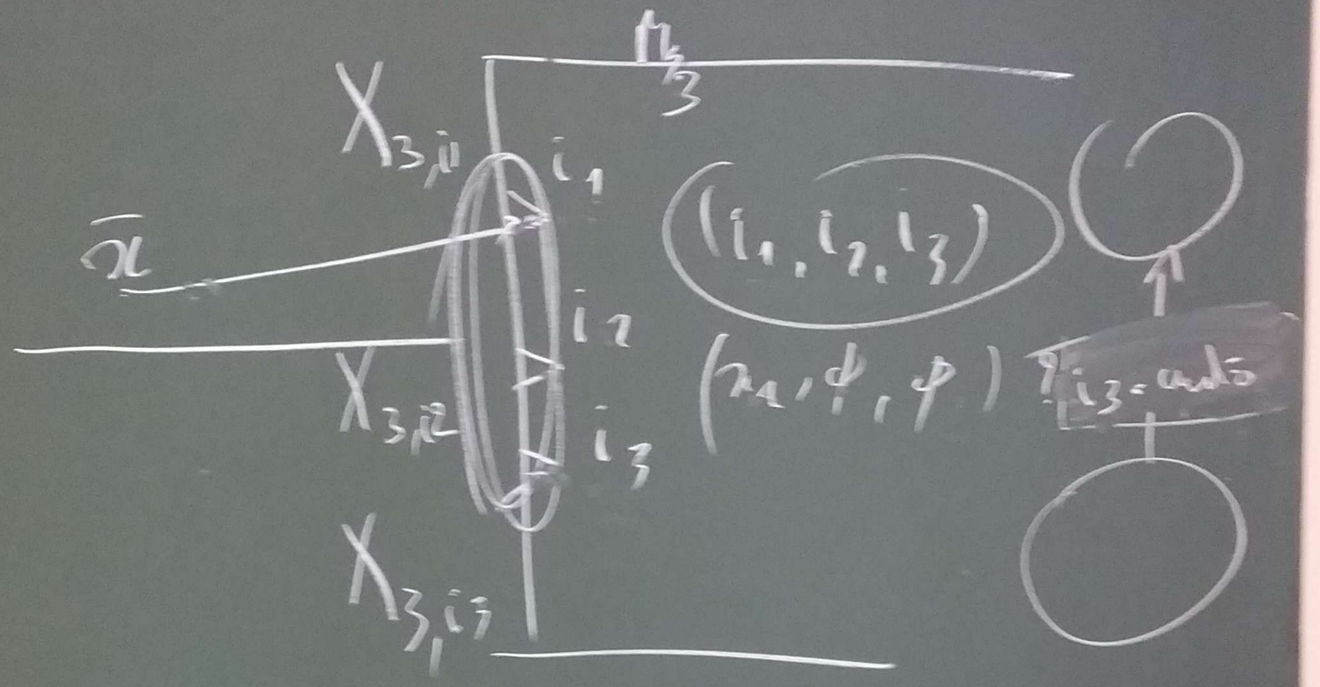
OUTER

HAREL
STATEMATE

ENTER/EXIT ACTIONS
ARE SYNTACTIC SUGAR







$$\bar{x} \in X_3 = X_{3,i_1} \times X_{3,i_2} \times X_{3,i_3}$$

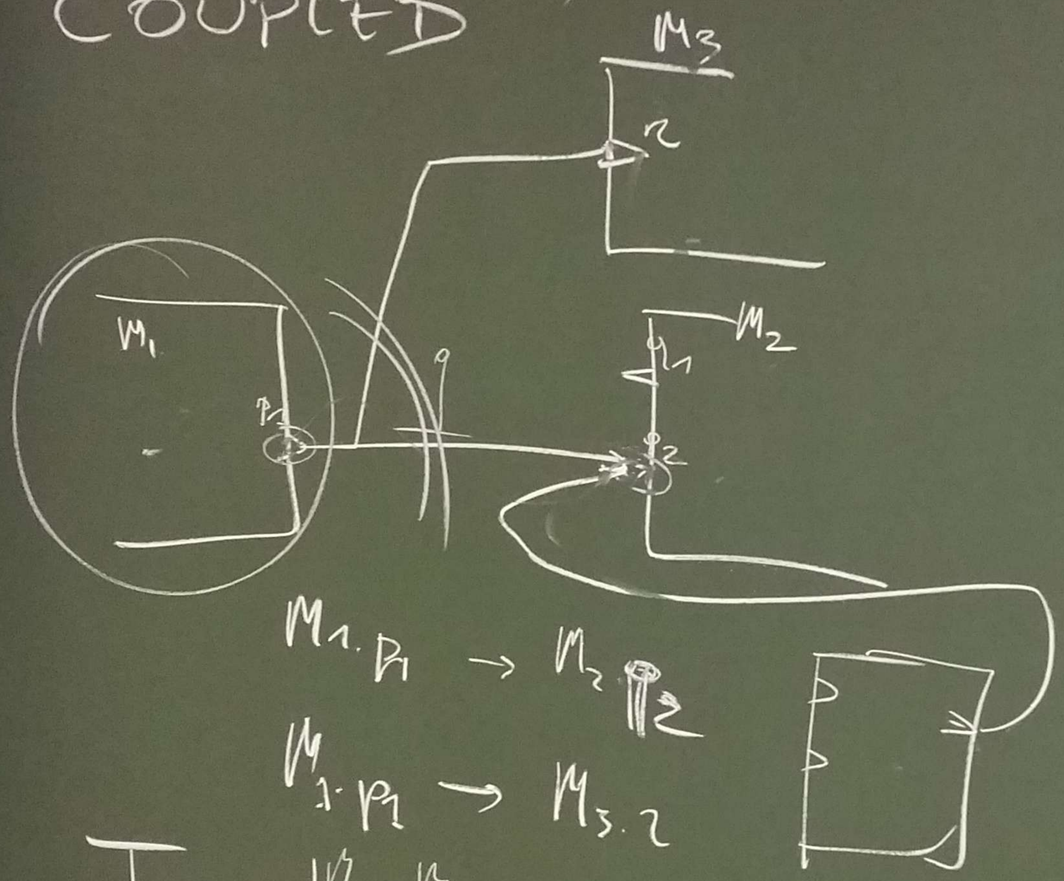
$$S = \bigtimes_{i \in D} Q_i$$

$$\underbrace{(a_1, a_2)}_{q_1} \underbrace{(a_3, a_4)}_{q_2}$$

$(\delta_{ext,2}(z_{2,1} \circ_e z_{1,2}(\lambda_1(p_1))), \phi)$

ATOMIC > DEVS

COUPLED

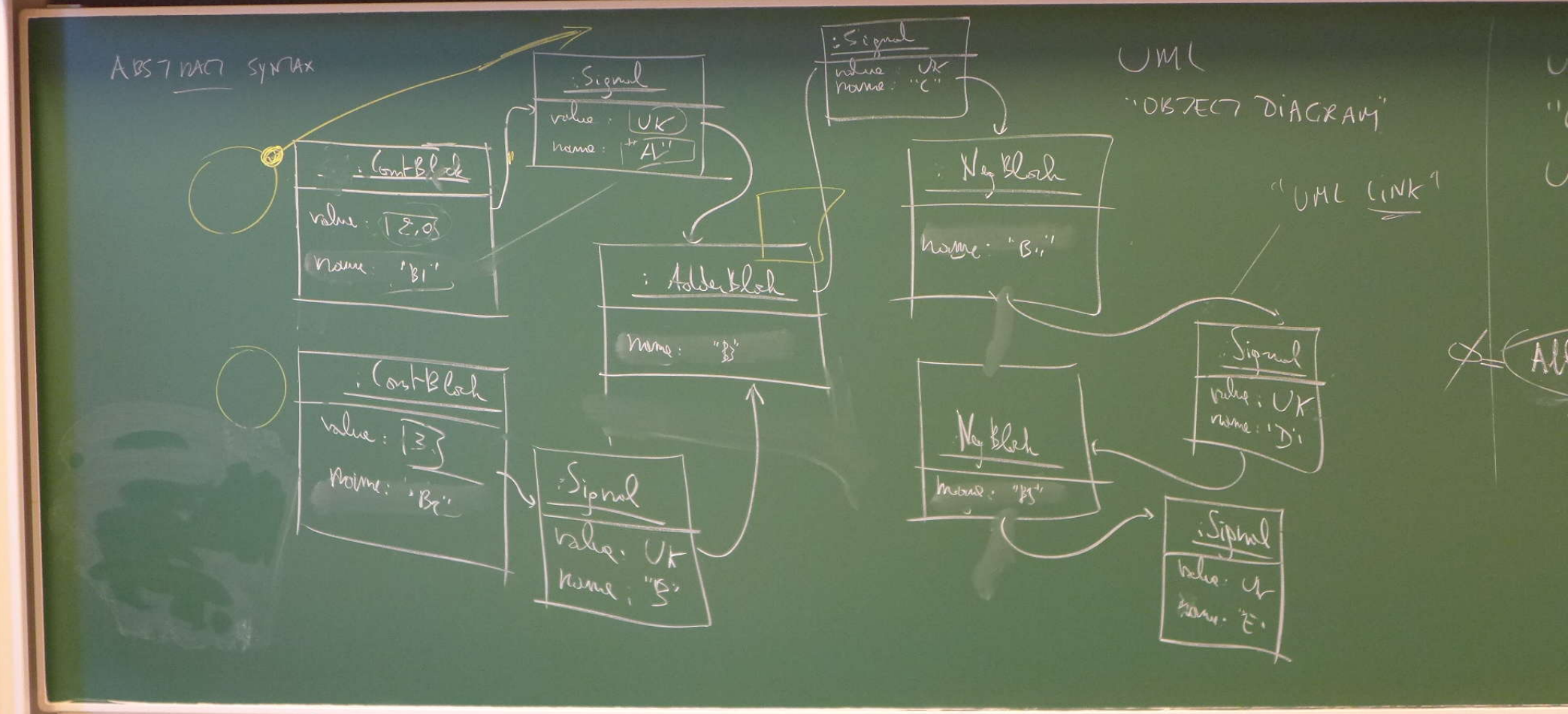


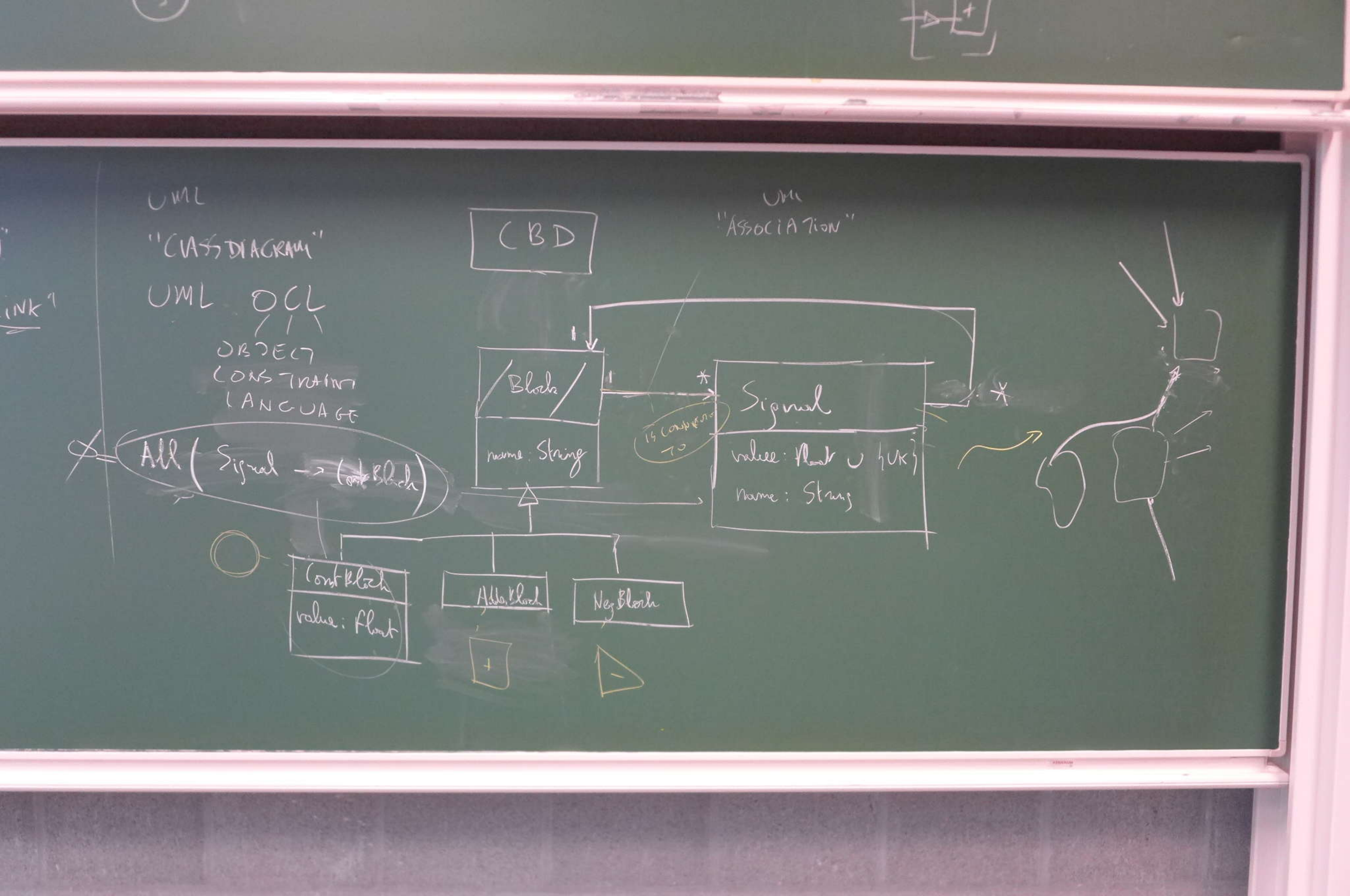
$M_{1.P_1} \rightarrow M_{2.P_2}$

$M_{1.P_1} \rightarrow M_{3.2}$

$I_{M_1} = \{M_2, M_3 \atop 3, 2\}$

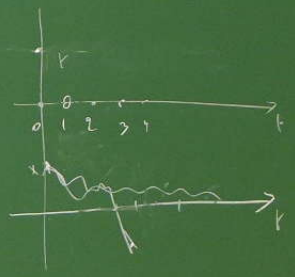
INFLUENCEES

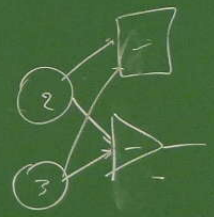

ABSTRACT SYNTAX
: ConstBlock
value : 2,05
name : "B1"
: Signal
value : UK
name : "A"
: ConstBlock
value : 3
name : "B2"
: Signal
value : UK
name : "B"
: AdderBlock
name : "B"
: Signal
value : UK
name : "C"
UML
"OBJECT DIAGRAM"
: NegBlock
name : "B1"
"UML LINK"
: NegBlock
name : "B2"
: Signal
value : UK
name : "D"
: Signal
value : UK
name : "E"

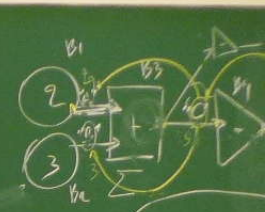

UML
"CLASS DIAGRAM"
UML OCL
OBJECT
CONSTRAINT
LANGUAGE
All(Signal --> ConstBlock)
CBD
Block
name : String
UML
"ASSOCIATION"
Signal
value : float ∪ {UK}
name : String
IS CONNECTED TO
ConstBlock
value : float
AdderBlock
NegBlock

CAUSAL BLOCK DIAGRAMS ((SYNCHRONOUS) DATA FLOW DIAGRAMS)

CBD	TIME	(VISUAL/TEXTUAL) CONCRETE SYNTAX	ABSTRACT SYNTAX	SEMANTICS: DENOTIONAL	SEMANTICS: OPERATIONAL
ALGEBRAIC	{NOW}	—			
DISCRETE-TIME	$\mathbb{N}$	—			
CONTINUOUS-TIME	$\mathbb{R}$	—			

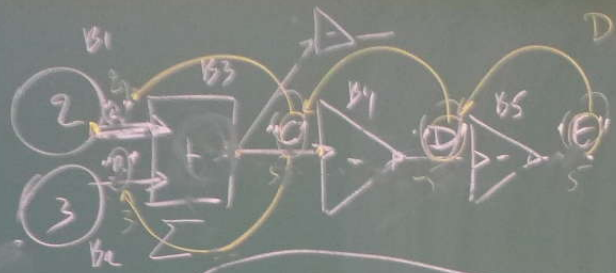






1 NEG
2 ADD
3 NEG
4 CONST
5 CONST

FLOW DIAGRAMS)



DEPENDENCY GRAPH

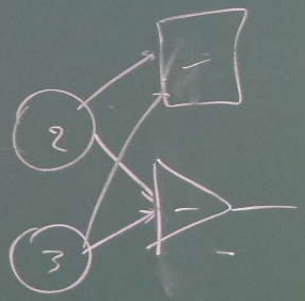
1	NEG	3	"E"
2	ADD	4,5	"C"
3	NEG	2	"D"
4	CONST	2	"A"
5	CONST	3	"B"

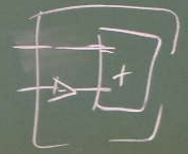
VISUAL

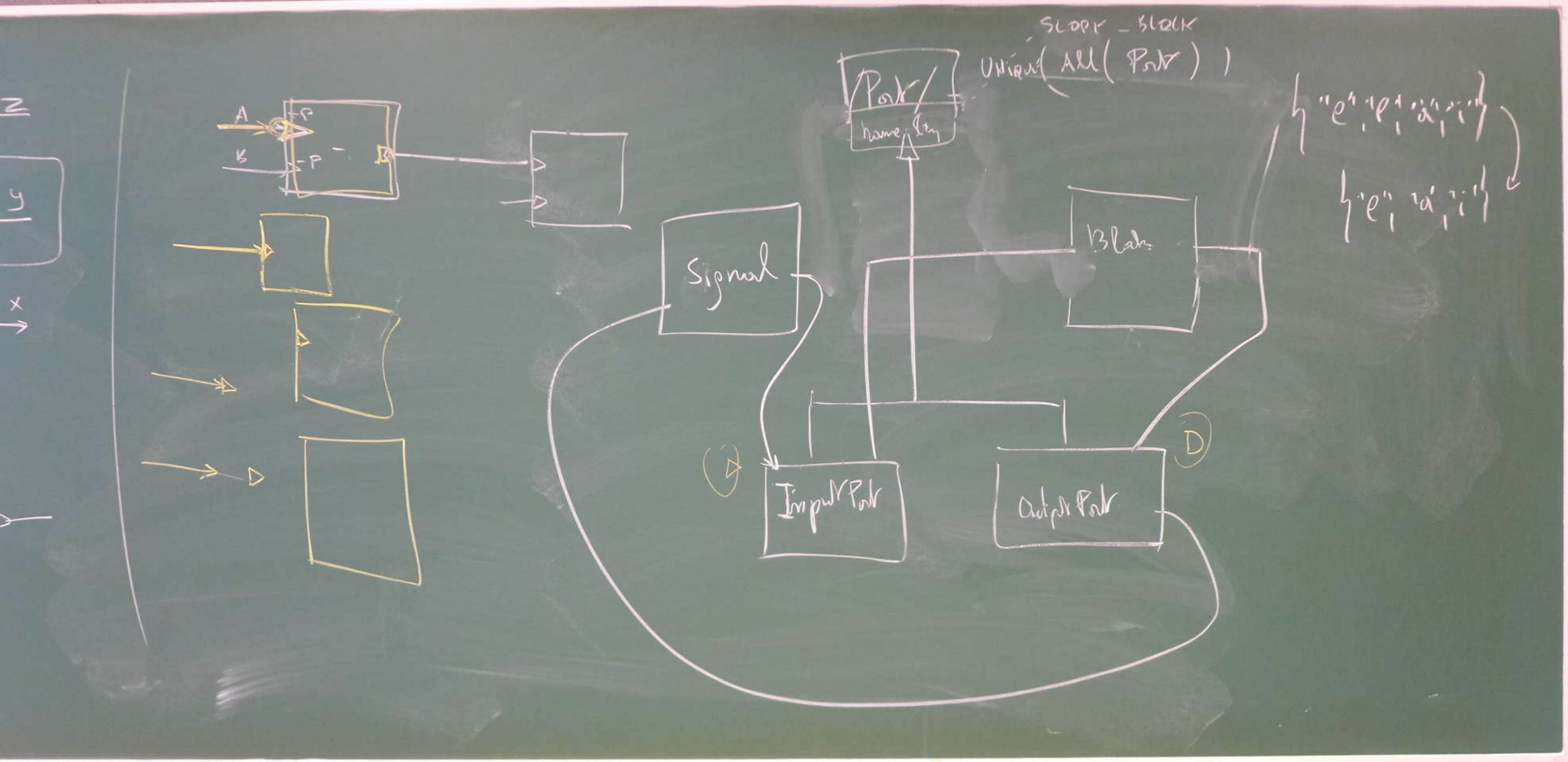
CSMP

TEXTUAL

CONCRETE SYNTAX

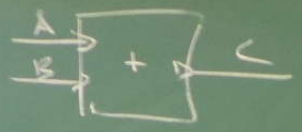


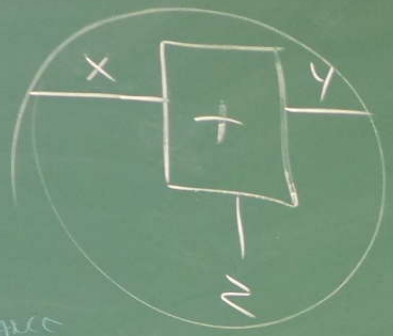



Port
Signal
Block
InputPort
OutputPort

CBD

ABD



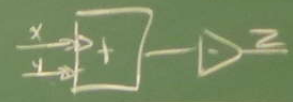


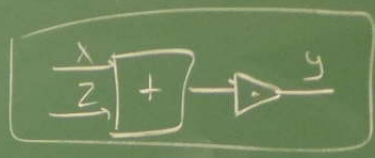
C := A + B

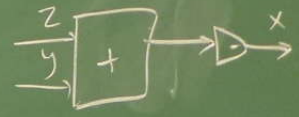
LHS RHS

$x + y + z = 0$

$z = -(x + y)$





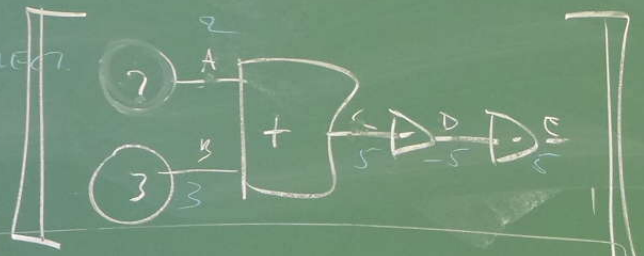


PERFORMANCE

HOW

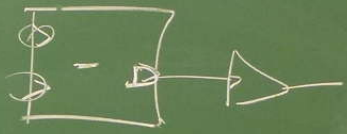
CONNECT

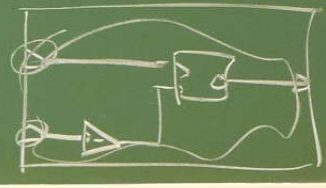
WHAT



MODELICA

=





$A, B, C, D, E \in \mathbb{R}$

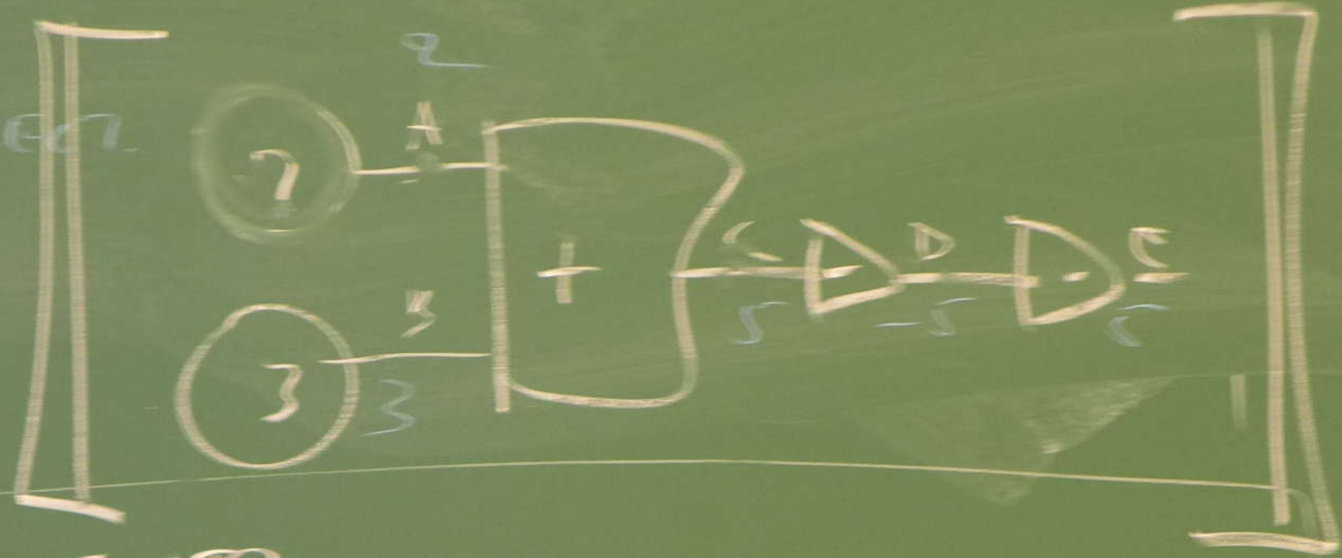
$B = 3, \quad C = A + B, \quad E = -D, \quad D = -C, \quad A = 2$

PERFORMANCE

HOW

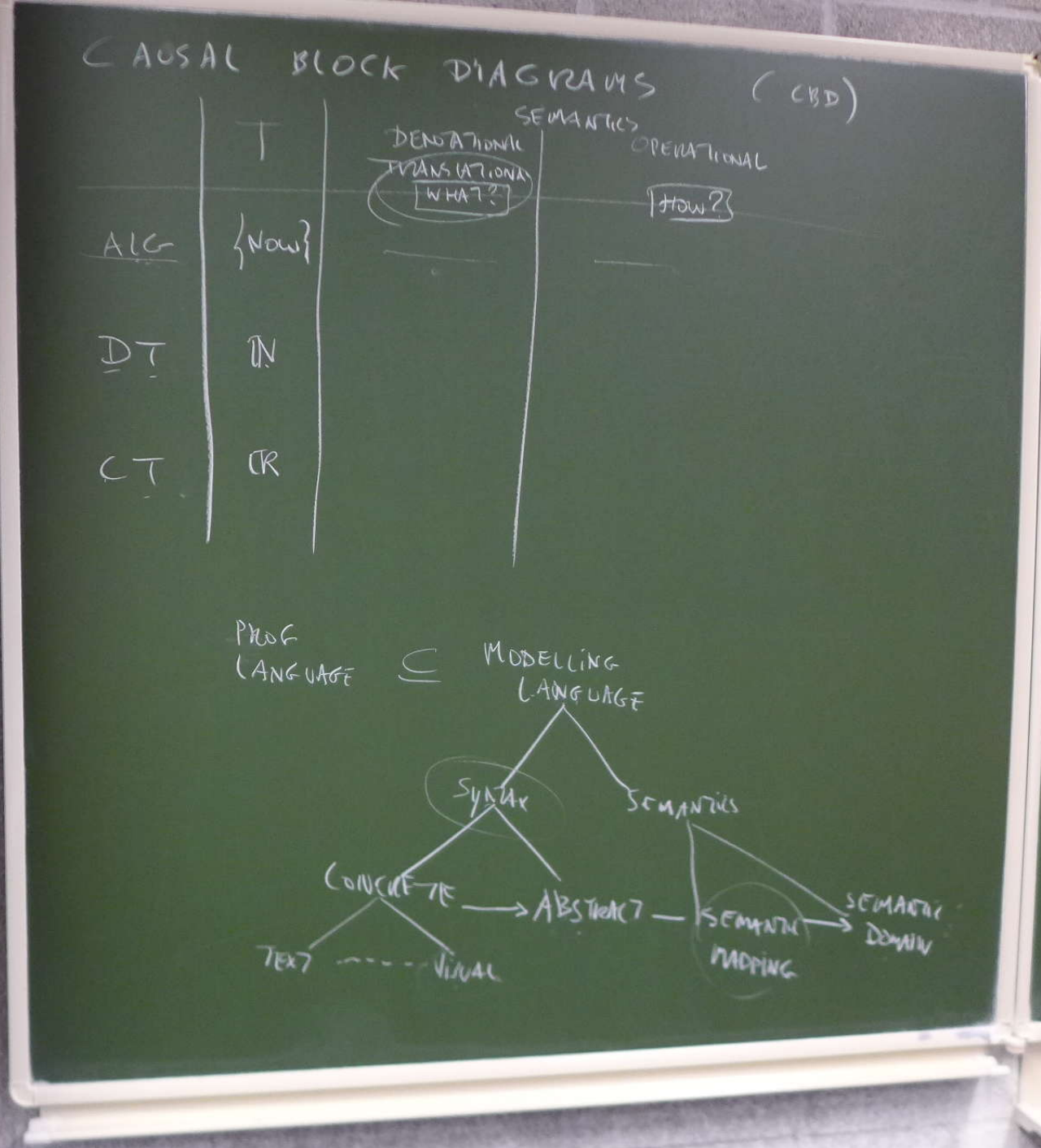
CONNECT

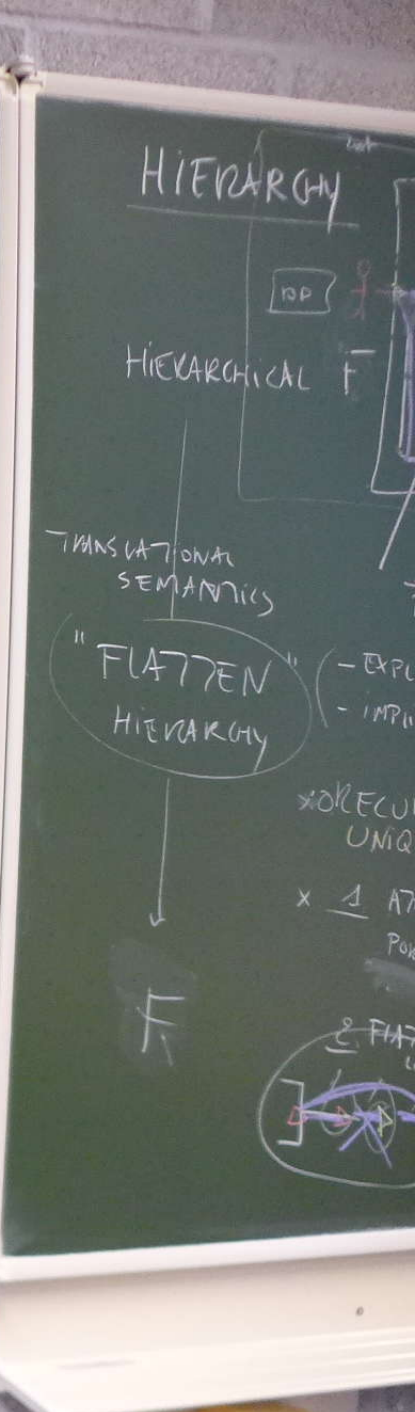
WHAT

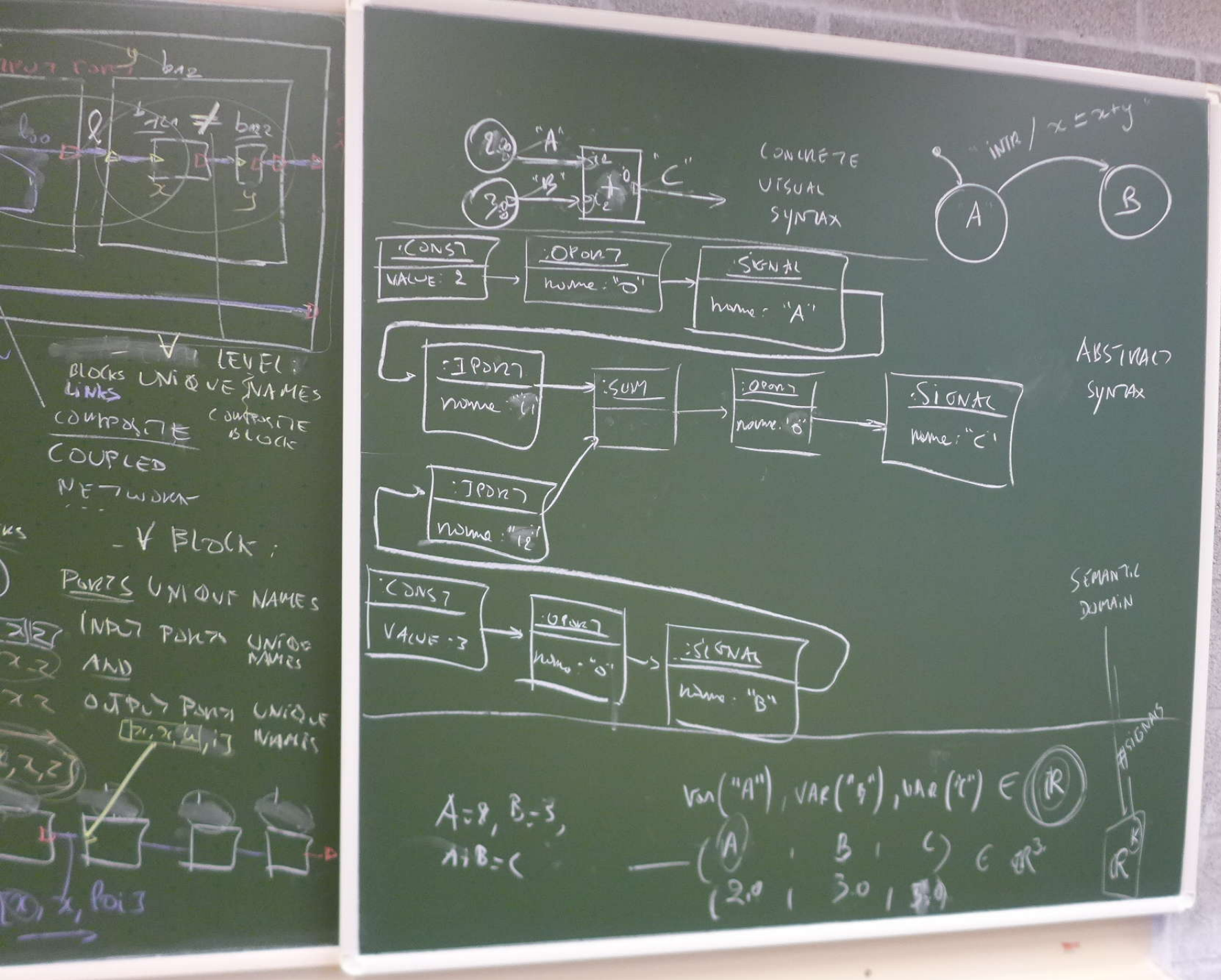


$$A, B, C, D, E \in \mathbb{R}$$

$$\{ B = 3,\ C = A + B,\ E = -D,\ D = -C,\ A = 2 \}$$


CAUSAL BLOCK DIAGRAMS (CBD)
T
SEMANTICS
DENOTATIONAL
TRANSLATIONAL
WHAT?
OPERATIONAL
HOW?
ALG
{NOW}
DT
IN
CT
CR
PROG LANGUAGE ⊂ MODELLING LANGUAGE
SYNTAX
SEMANTICS
CONCRETE
ABSTRACT
TEXT
VISUAL
SEMANTIC MAPPING
SEMANTIC DOMAIN


HIERARCHY
HIERARCHICAL
TRANSLATIONAL SEMANTICS
"FLATTEN" HIERARCHY


"A"
"B"
"C"
CONCRETE VISUAL SYNTAX
:CONST
VALUE: 2
:OPORT
name: "O"
:SIGNAL
name: "A"
:IPORT
name: "i"
:SUM
:OPORT
name: "O"
:SIGNAL
name: "C"
:IPORT
name: "i2"
:CONST
VALUE: -3
:OPORT
name: "O"
:SIGNAL
name: "B"
INIT / x = x+y
A
B
ABSTRACT SYNTAX
SEMANTIC DOMAIN
#SIGNALS
A=8, B=-3,
A;B=(
VAR("A"), VAR("B"), VAR("C") ∈ IR
(A, B, C) ∈ IR³
(2.0, 3.0,
LEVEL:
BLOCKS UNIQUE NAMES
LINKS
COMPOSITE
COMPOSITE BLOCK
COUPLED
NETWORK
- ∀ BLOCK:
PORTS UNIQUE NAMES
INPUT PORTS UNIQUE NAMES
AND
OUTPUT PORTS UNIQUE NAMES

HIERARCHY

HIERARCHICAL

TRANSLATIONAL SEMANTICS

"FLATTEN HIERARCHY"

F

ATOMIC
PRIMITIVE

LINK
CONNECTION

COMPOSITE
COUPLED
NETWORK

- ∀ LEVEL:
  BLOCKS UNIQUE NAMES
  LINKS
  COMPOSITE BLOCK

- EXPLICITLY (TRACEABILITY) NAMES
- IMPLICITLY (MODIFY OPSEM OF FLAT F)

IDENTIFIERS

RECURSIVELY UNIQUE BLOCK NAMES
- PORT NAMES
- LINK NAMES

× 1 ATOMIC BLOCKS

PORTS

- ∀ BLOCK:
  PORTS UNIQUE NAMES
  INPUT PORTS UNIQUE NAMES
  AND
  OUTPUT PORTS UNIQUE NAMES

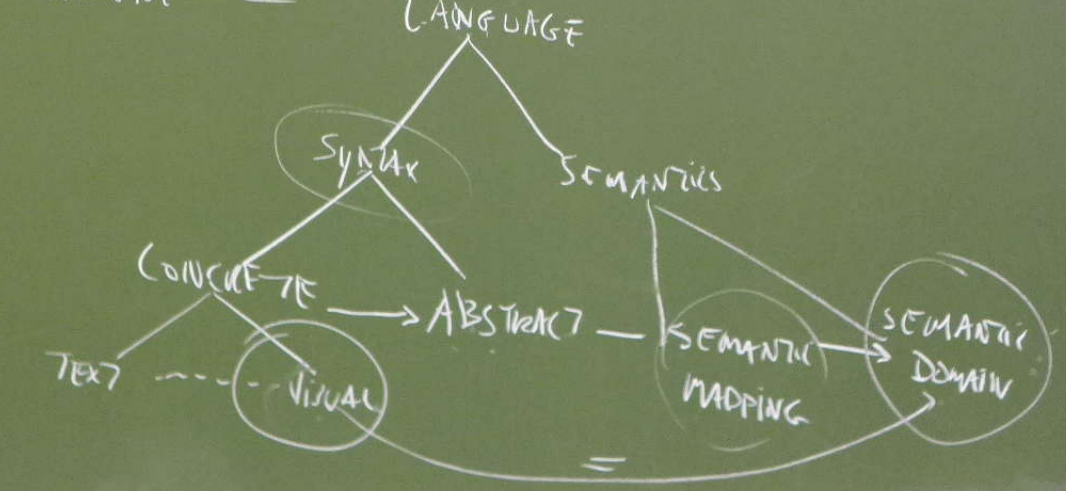
& FLATTEN LINKS

CAUSAL BLOCK DIAGRAMS (CBD)

	T	SEMANTICS: DENOTATIONAL / TRANSLATIONAL — WHAT?	SEMANTICS: OPERATIONAL — HOW?
ALG	{NOW}		
DT	IN		
CT	CR		

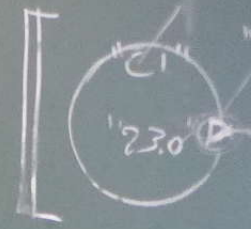
- TIME EFFICIENCY
- SEQUENTIAL

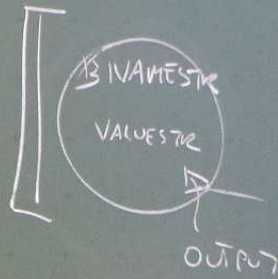
PROG LANGUAGE ⊂ MODELLING LANGUAGE

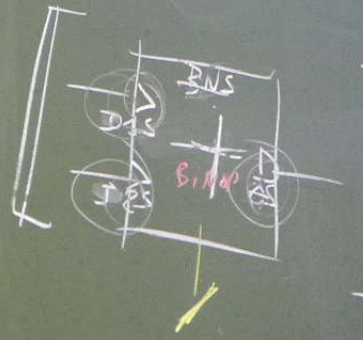


ALG-CBD

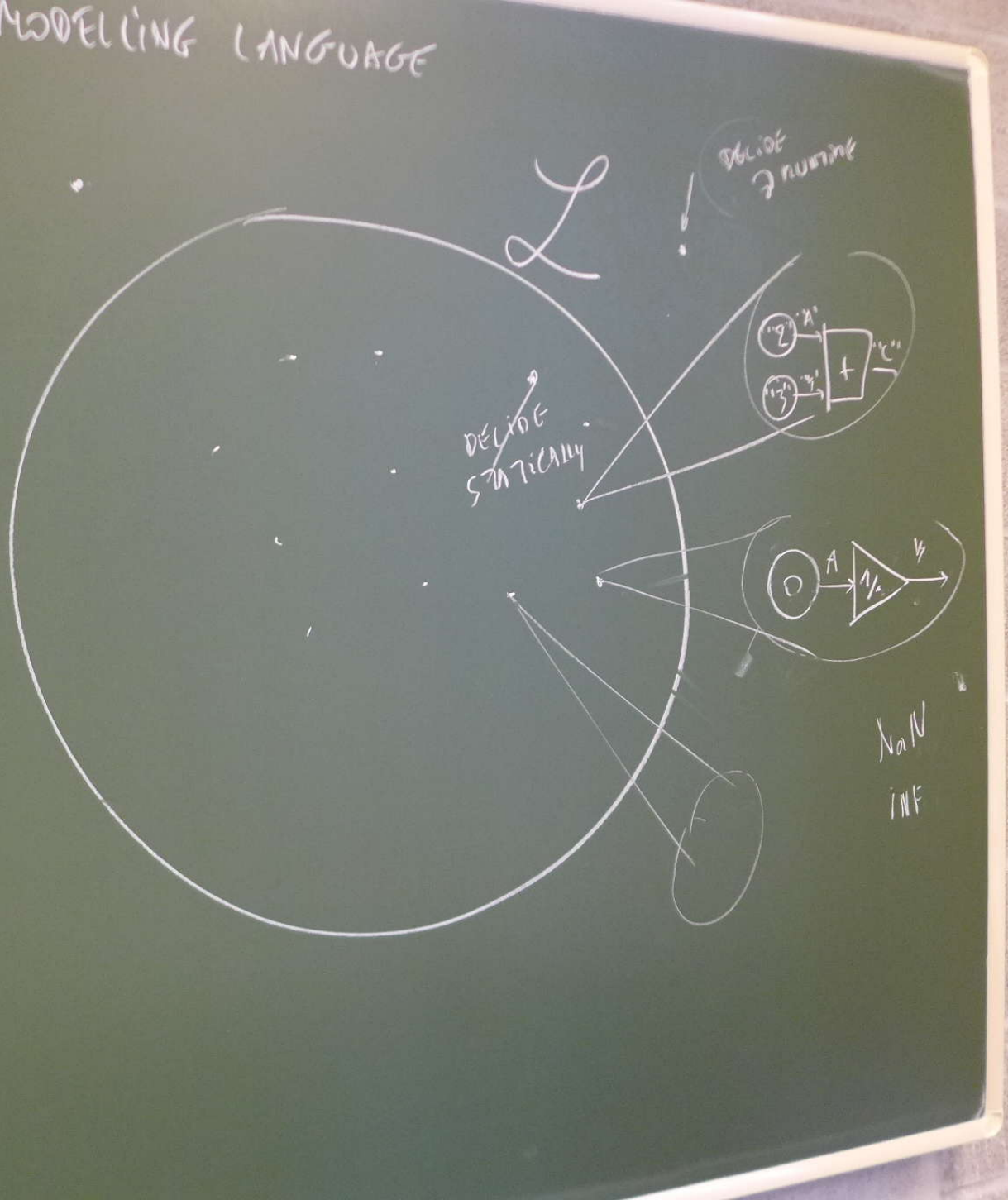
① BASIC BLOCKS

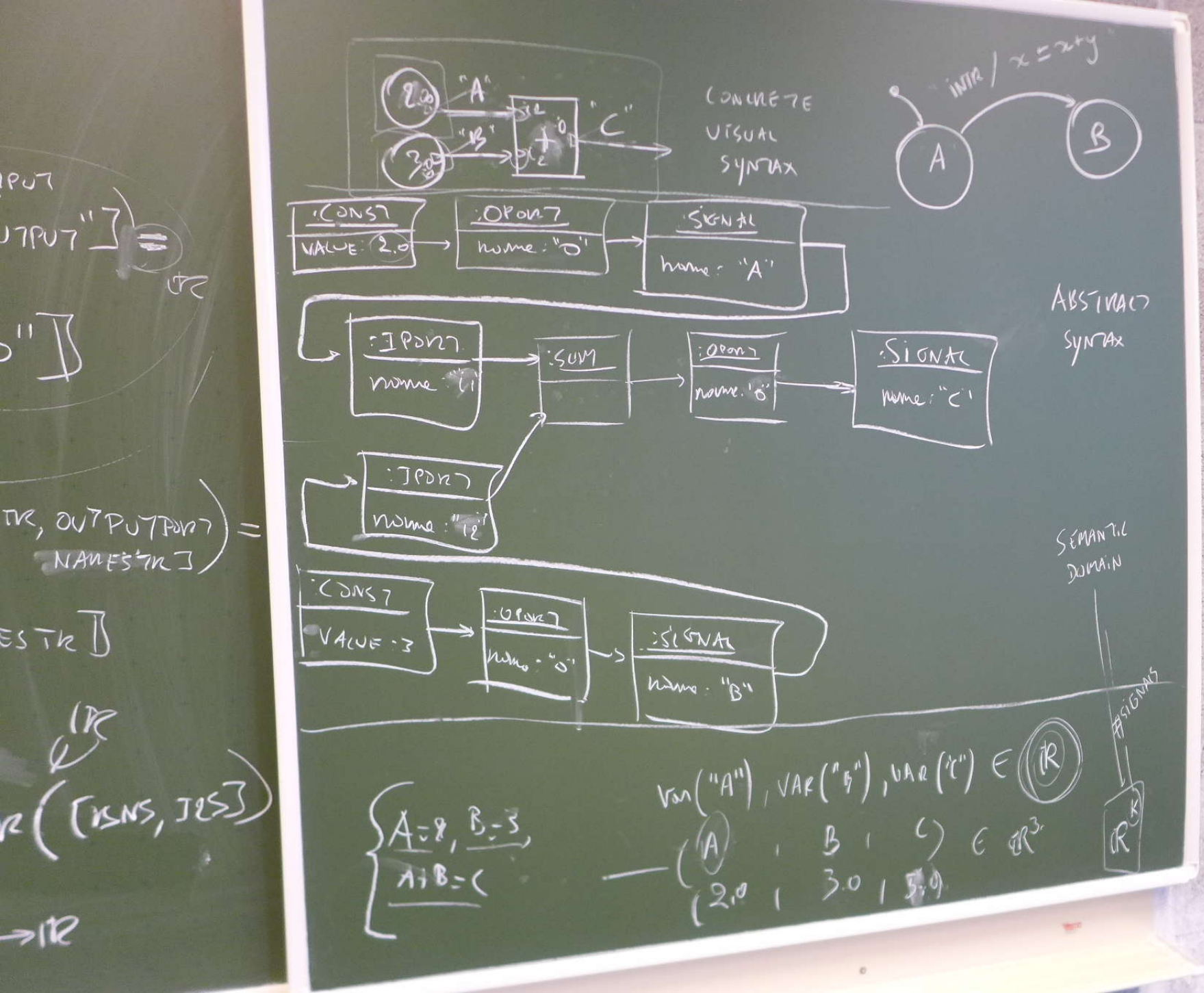


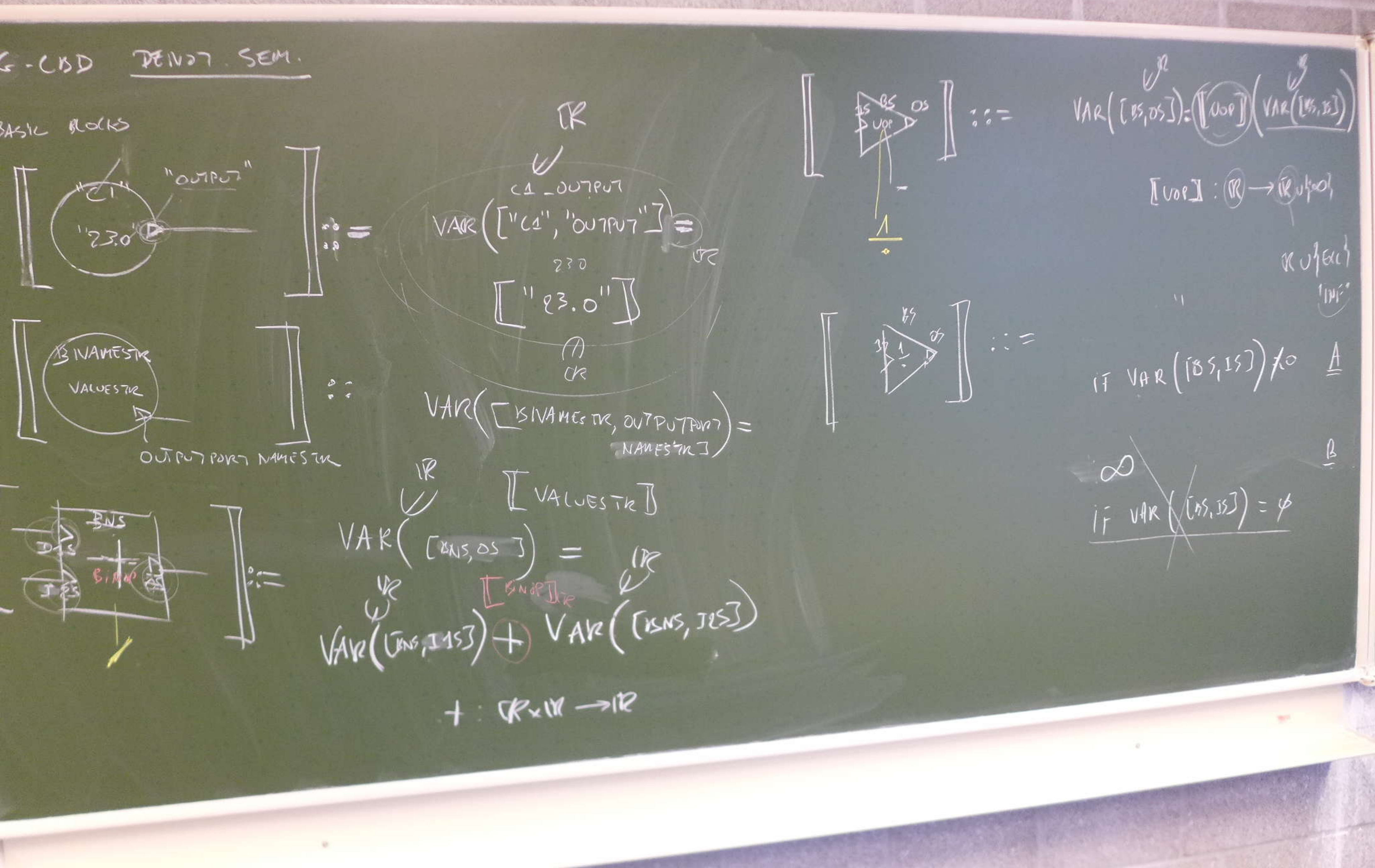


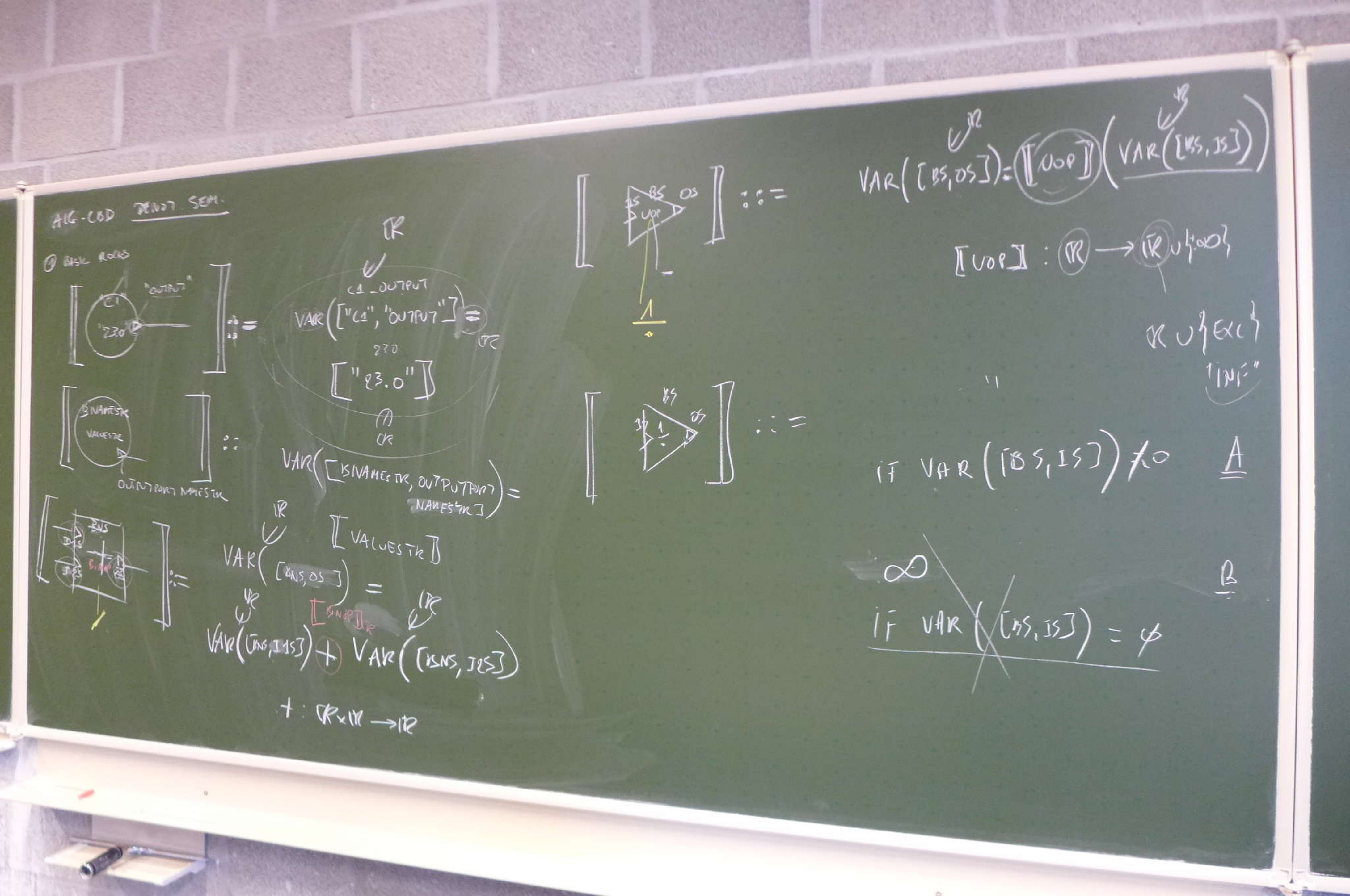


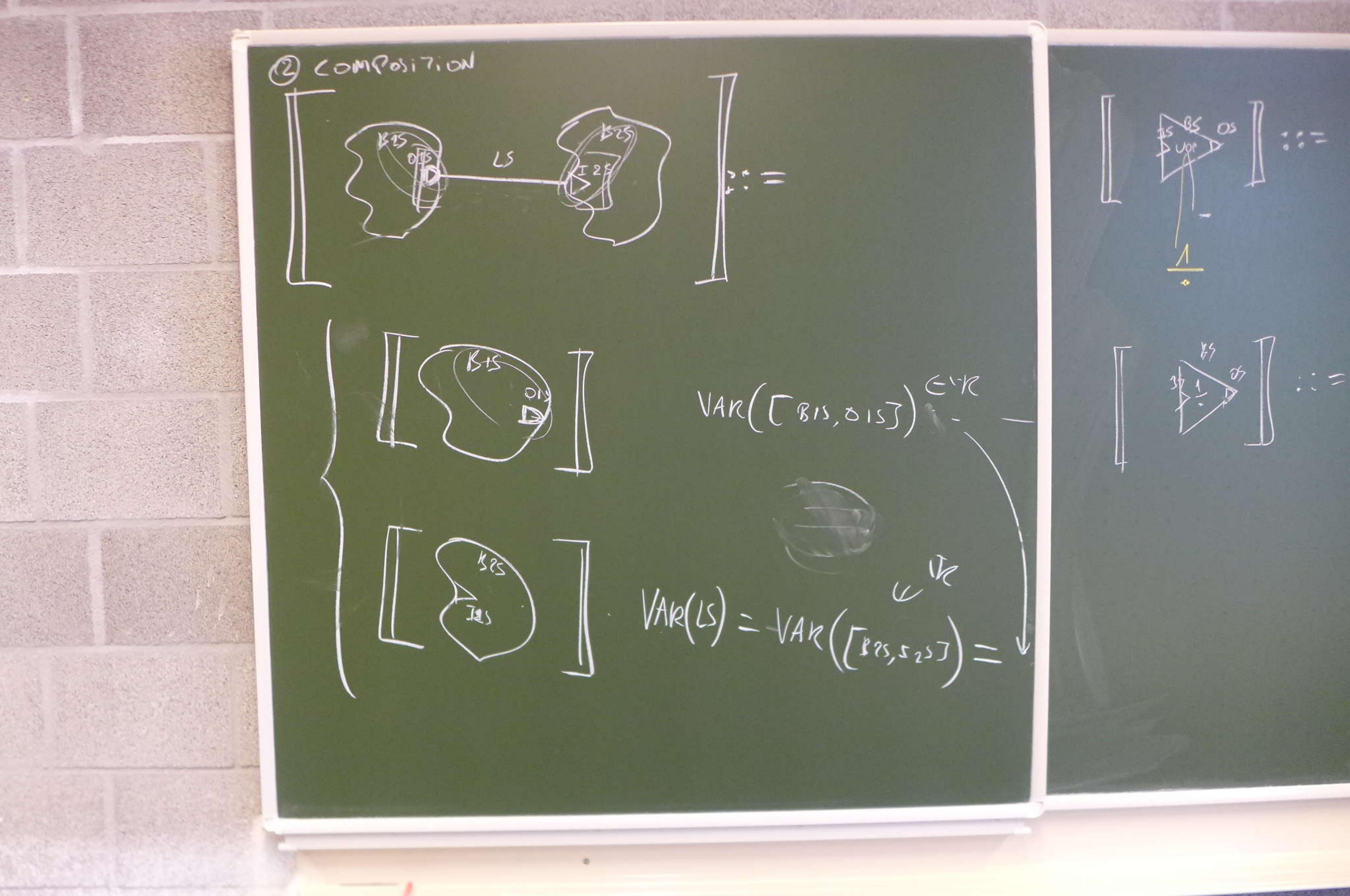
MODELLING LANGUAGE




"A"
"B"
"C"
CONCRETE VISUAL SYNTAX
INTR / x = 2+y
A
B
:CONST
VALUE: 2.0
:OPORT
name: "O"
:SIGNAL
name: "A"
ABSTRACT SYNTAX
:IPORT
name: "I"
:SUM
:OPORT
name: "O"
:SIGNAL
name: "C"
:IPORT
name: "I2"
:CONST
VALUE: 3
:OPORT
name: "O"
:SIGNAL
name: "B"
SEMANTIC DOMAIN
#SIGNALS
A=8, B=5
A+B=C
VAR("A"), VAR("B"), VAR("C") ∈ IR
(A, B, C) ∈ IR^3
(2.0, 3.0, 5.0)
IR^K


G-CBD DENOT. SEM.
BASIC BLOCKS
"C1"
"OUTPUT"
"23.0"
::=
C1_OUTPUT
VAR(["C1", "OUTPUT"]) =
23.0
["23.0"]
BSNAMESTR
VALUESTR
OUTPUTPORT NAMESTR
VAR([BSNAMESTR, OUTPUTPORTNAMESTR]) =
[VALUESTR]
BNS
VAR([BNS, OS]) =
VAR([BNS, I1S]) + VAR([BNS, I2S])
+ : ℝ × ℝ → ℝ
::=
VAR([BS, OS]) = [UOP](VAR([BS, IS]))
[UOP] : ℝ → ℝ ∪ {∞}
IF VAR([BS, IS]) ≠ 0
IF VAR([BS, IS]) = 0


AIG-CBD DENOT SEM.
BASIC BLOCKS
"C1"
"OUTPUT"
"23.0"
VAR(["C1", "OUTPUT"]) =
C1_OUTPUT
["23.0"]
NAMESTR
VALUESTR
OUTPUTPORT NAMESTR
VAR([BSIVNAMESTR, OUTPUTPORTNAMESTR]) =
[[VALUESTR]]
VAR([BNS,OS]) =
VAR([BNS,I1S]) + VAR([BSNS, I2S])
+ : IR x IR → IR
VAR([BS,OS]) = [[UOP]](VAR([BS,IS]))
[[UOP]] : IR → IR ∪ {∞}
IR ∪ {EXC}
"INF"
IF VAR([BS,IS]) ≠ 0
A
IF VAR([BS,IS]) = φ
B


② COMPOSITION
B1S
O1S
LS
B2S
I2S
::=
B1S
O1S
VAR([B1S, O1S]) ∈ VR
B2S
I2S
VAR(LS) = VAR([B2S, S2S]) =
BS
IS
OS
UOP
::=
BS
IS
OS
1
::=

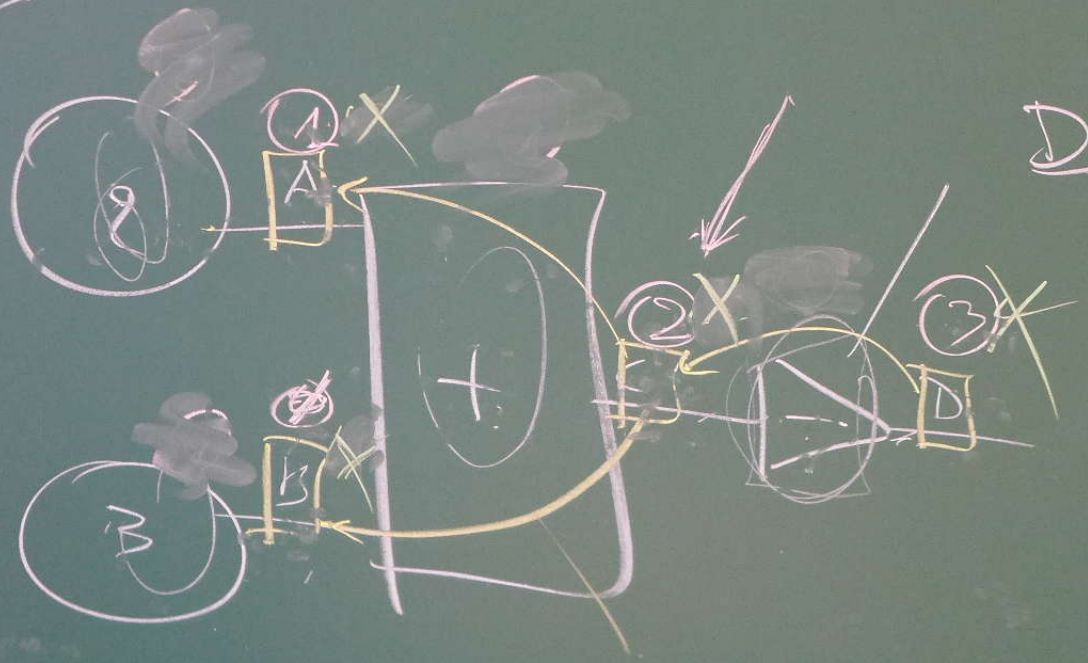
ALG · CBD

DENOTATIONAL

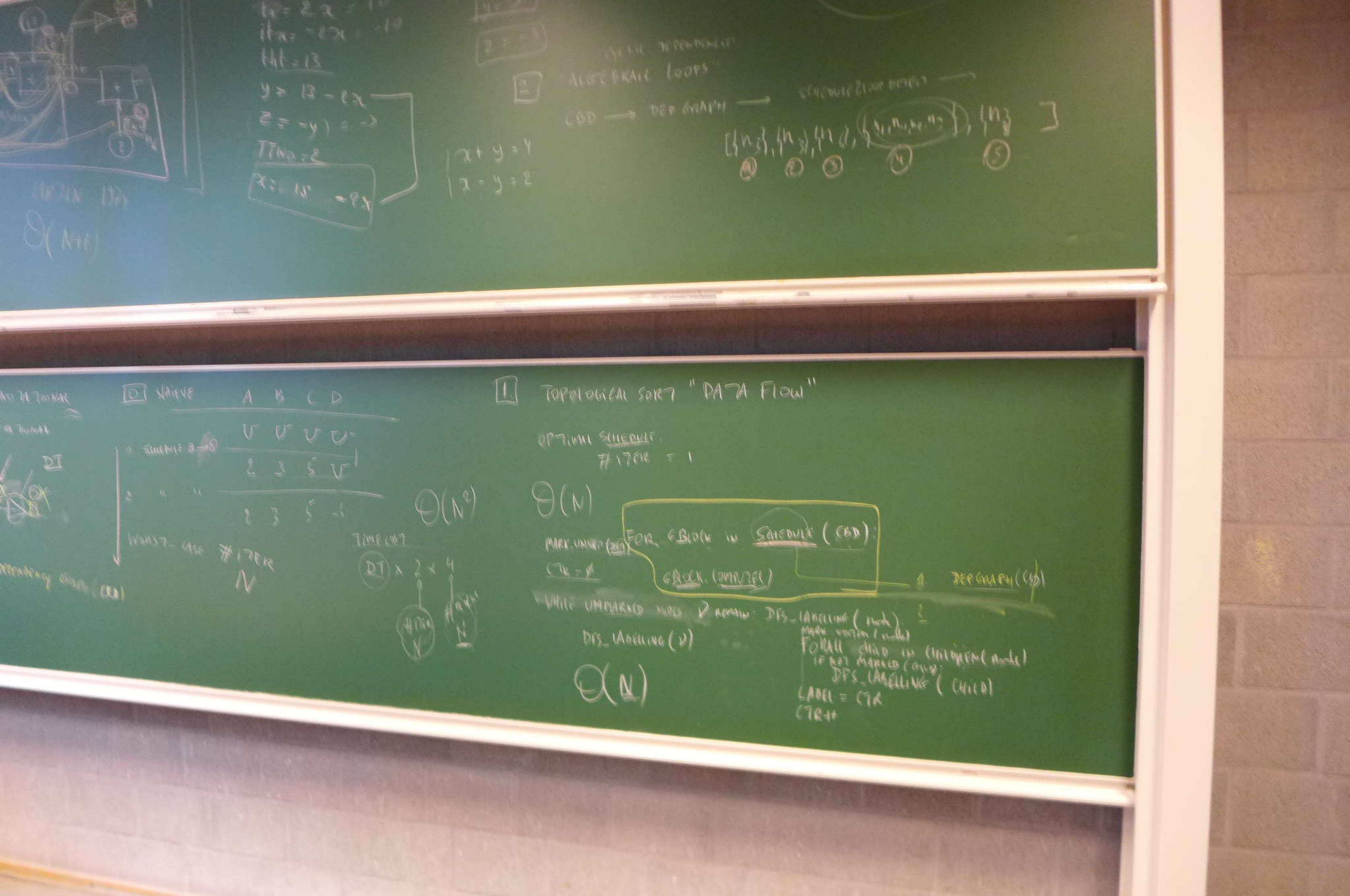
≈

OPERATIONAL

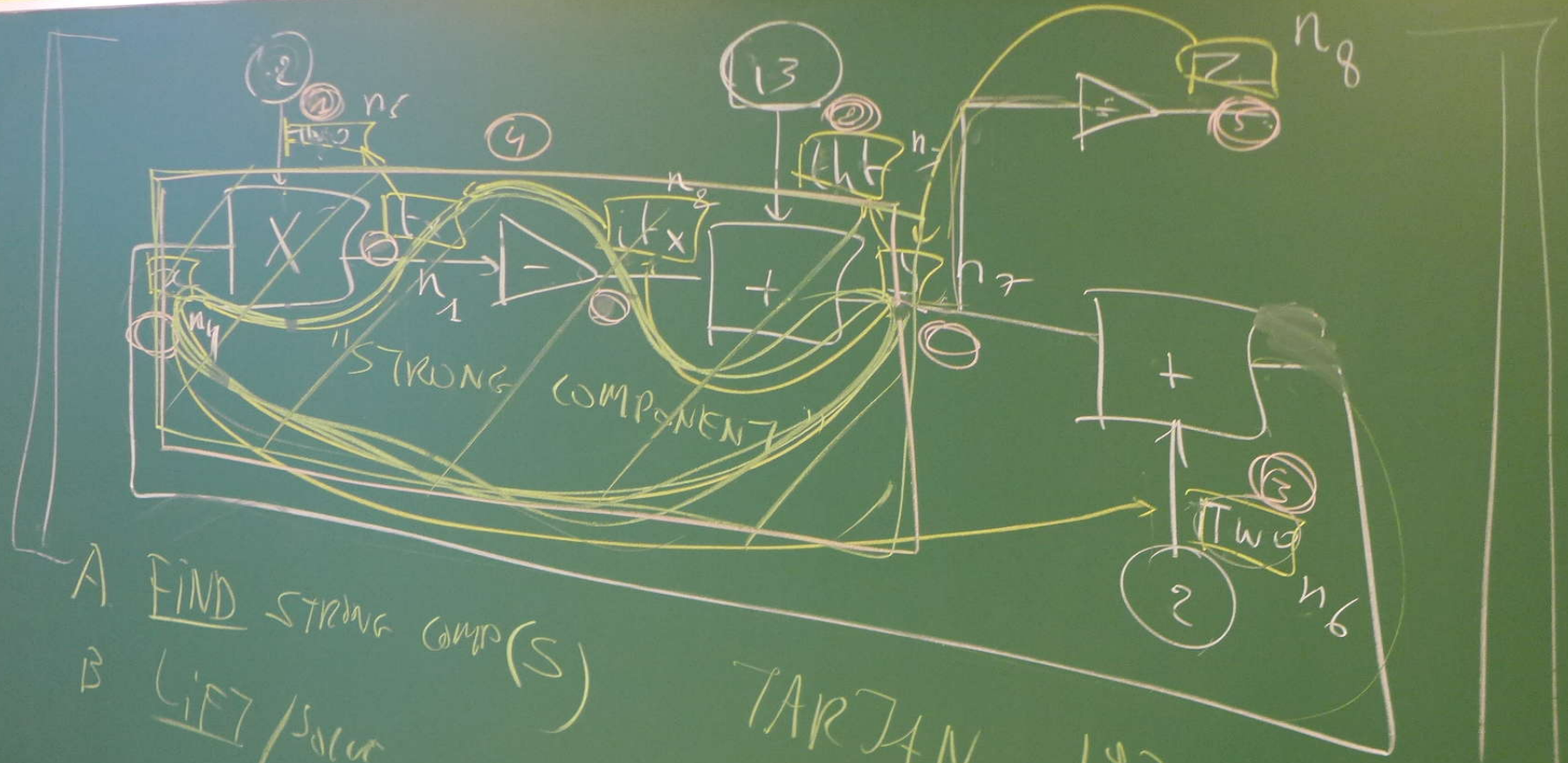
CBD



DEPENDENCY GRAPH (CBD)



"ALGEBRAIC LOOPS"
CBD → DEP GRAPH
x + y = 4
x − y = 2
Θ(N²)
WORST-CASE #ITER
N
TIME COST
DT × 2 × 4
[1] TOPOLOGICAL SORT "DATA FLOW"
OPTIMAL SCHEDULE
#ITER = 1
Θ(N)
FOR GBLOCK IN SCHEDULE (CBD):
GBLOCK.COMPUTE()
MARK UNMARKED
CTR = 0
DEP GRAPH (CBD)
WHILE UNMARKED NODES REMAIN: DFS_LABELLING (node)
DFS_LABELLING (V)
Θ(N)
FORALL CHILD IN CHILDREN (node)
IF NOT MARKED (child):
DFS_LABELLING (CHILD)
LABEL = CTR
CTR++



A FIND STRONG COMPS (S)

B LIFT / PACK

TARJAN 1974

$O(N+E)$

TWO = 2

tx = 2x = 10

itx = -2x = -10

tht = 13

y = 13 - 2x

(z = -y) = -3

TTWO = 2

x = 15 - 2x

$$\begin{cases} x + y = 4 \\ x - y = 2 \end{cases}$$

3x = 15

x = 5

y = 3

z = -3

(x, y, z; - -

2

CYCLIC DEPEND

ALGEBRAIC LOOP

CBD ⟶ DEP GR

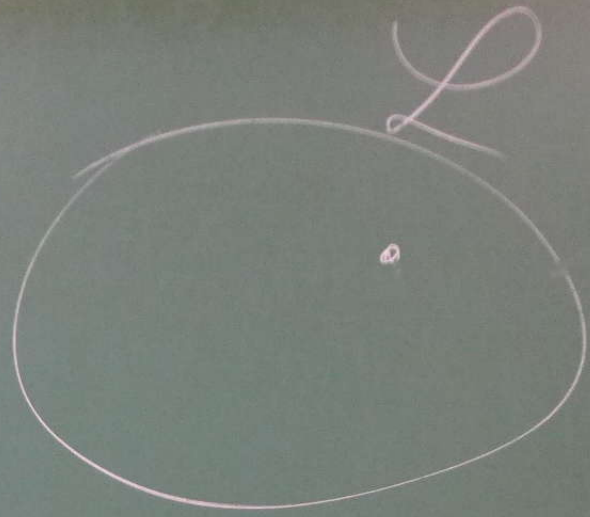
$3x = 15$

$x = 5$

$y = 3$

$z = -3$

$(x, y, z, \ldots) \in \mathbb{R}^{dx}$



CYCLIC DEPENDENCIES

2 "ALGEBRAIC LOOPS"

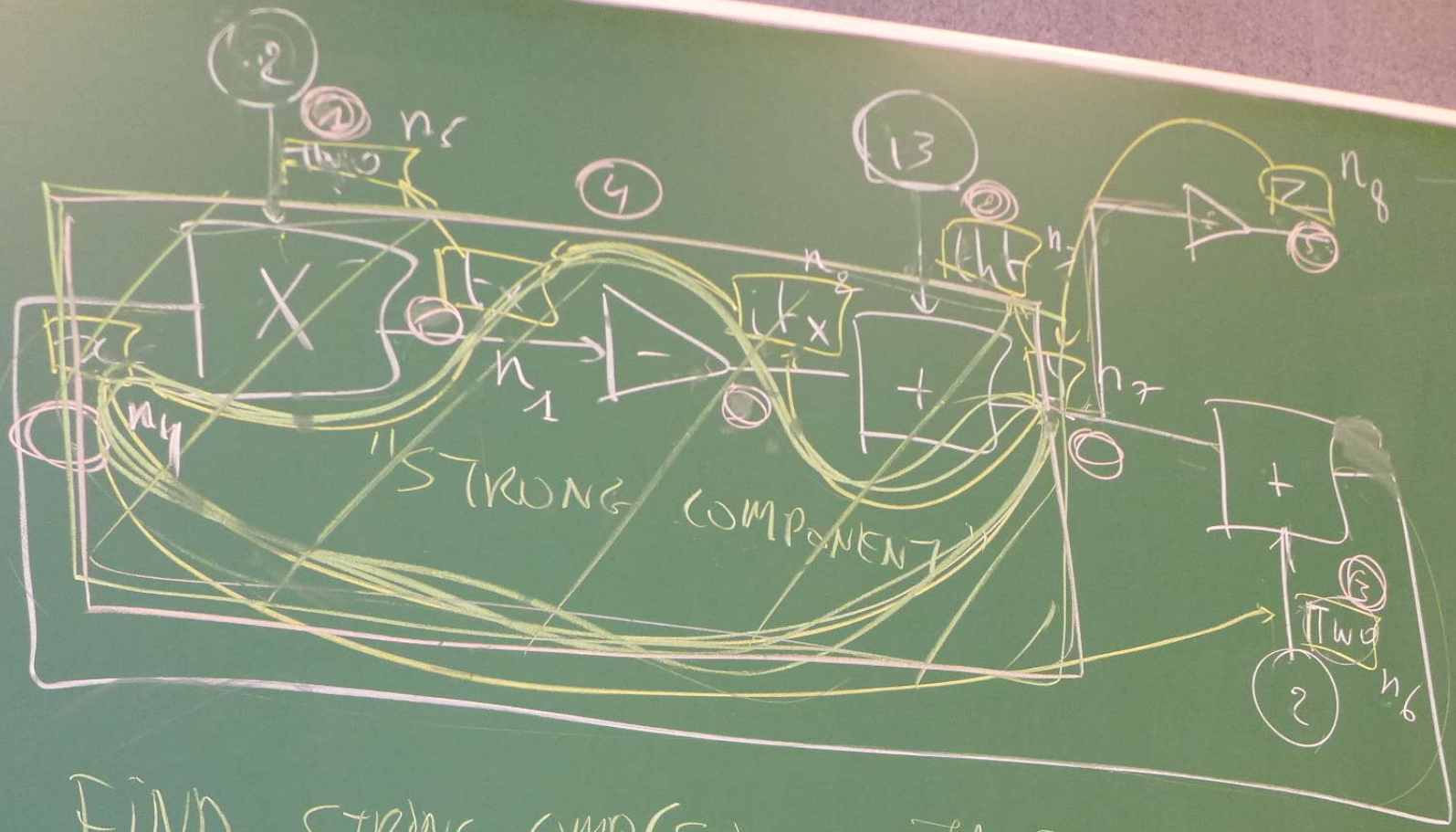
CBD ⟶ DEP GRAPH ⟶ SCHEDULE & LOOP DETECT ⟶

$x + y = 4$

$x - y = 2$

$[\{n_5\}, \{n_3\}, \{n_6\}, \{n_1, n_4, n_2, n_7\}, \{n_8\}]$

① ② ③ ④ ⑤



A FIND STRONG COMP(S) TARJAN 1974

B LIFT / Solve $\Theta(N+E)$

TWO = 2

$t_x = 2x = 10$

$it_x = -2x = -10$

$tht = 13$

$y = 13 - 2x$

$(z = -y) = -3$

$TTWO = 2$

$x = 15 - 2x$

GAUSS ELIMINATION

$1x + 1y = 4$

$1x - 1y = 2$

$\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 4 \\ 2 \end{bmatrix}$

$3x = 15$

$x = 5$

$y = 3$

$z = -3$

2

$(x, y, z, -) \in \mathbb{R}^4$

CYCLIC DEPENDENCIES

"ALGEBRAIC LOOPS"

CBD → DEP GRAPH → SCHEDULE (LOOP DETECT) →

$\sin(x^2) + \tan(y \times z) = y$

$x - y = 2$

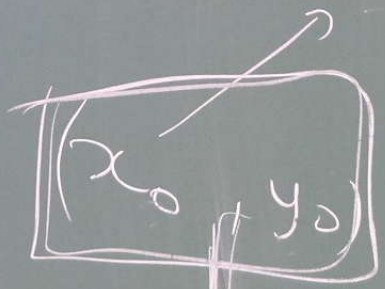
$|G| \neq 0$

$x = \frac{\begin{vmatrix} 4 & 1 \\ 2 & -1 \end{vmatrix}}{\begin{vmatrix} 1 & 1 \\ 1 & -1 \end{vmatrix}}$

$y = \frac{\begin{vmatrix} 1 & 4 \\ 1 & 2 \end{vmatrix}}{\begin{vmatrix} 1 & 1 \\ 1 & -1 \end{vmatrix}}$

CRAMER

$$\begin{cases} \sin(x_0^2) + \tan(x_0 \cdot y_0) - y_0 = \varepsilon_1 \\ \cos(\sqrt{x_0 - y_0^2}) = z \end{cases} = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix}$$



RESIDU

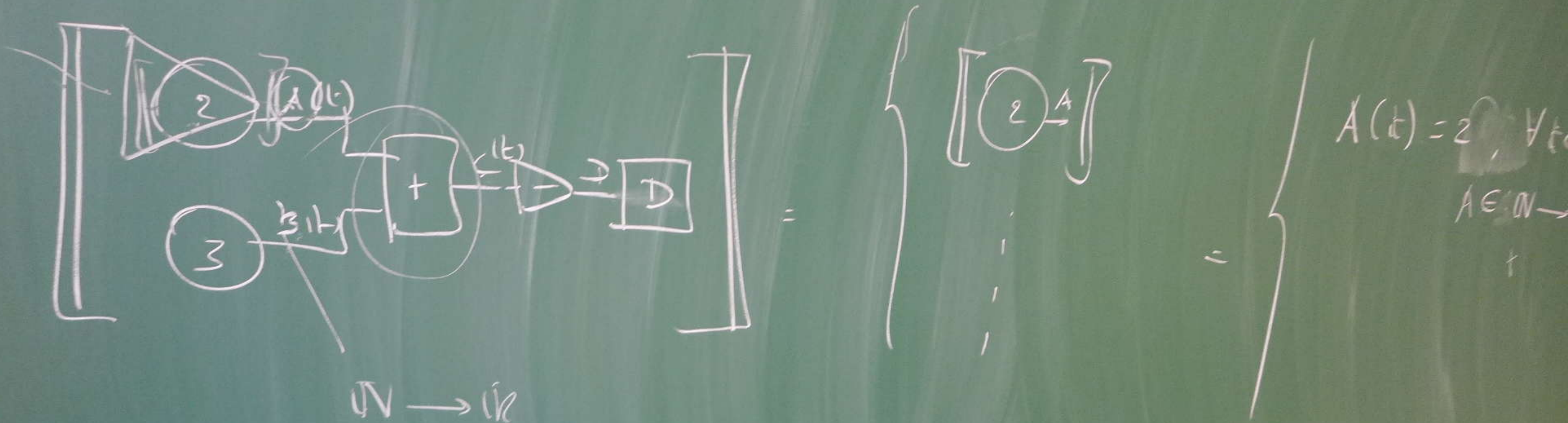
$\varepsilon_1^0 \; \varepsilon_1^0$

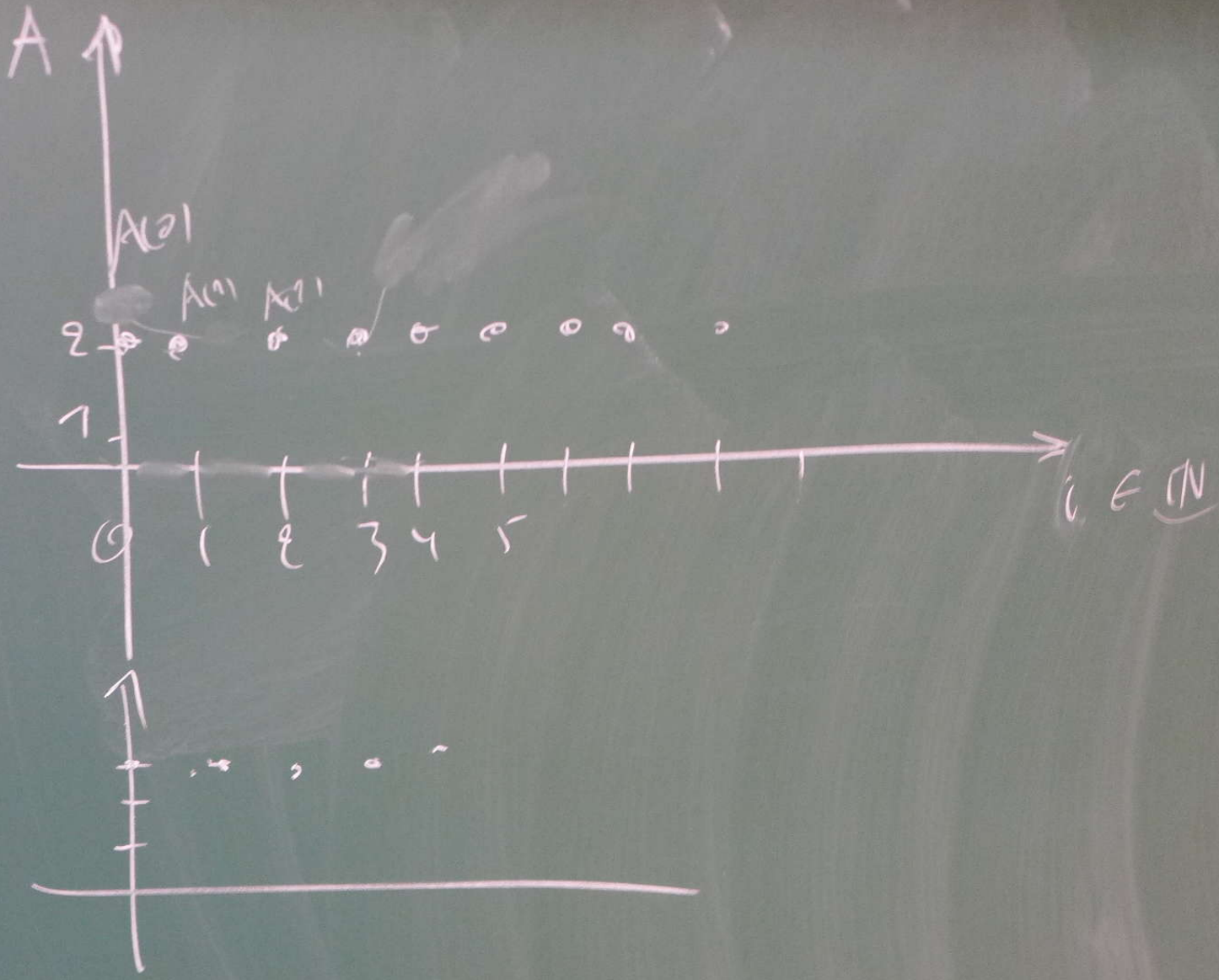
$(x_1, y_1) \longrightarrow \varepsilon_1' \; \varepsilon_1'$

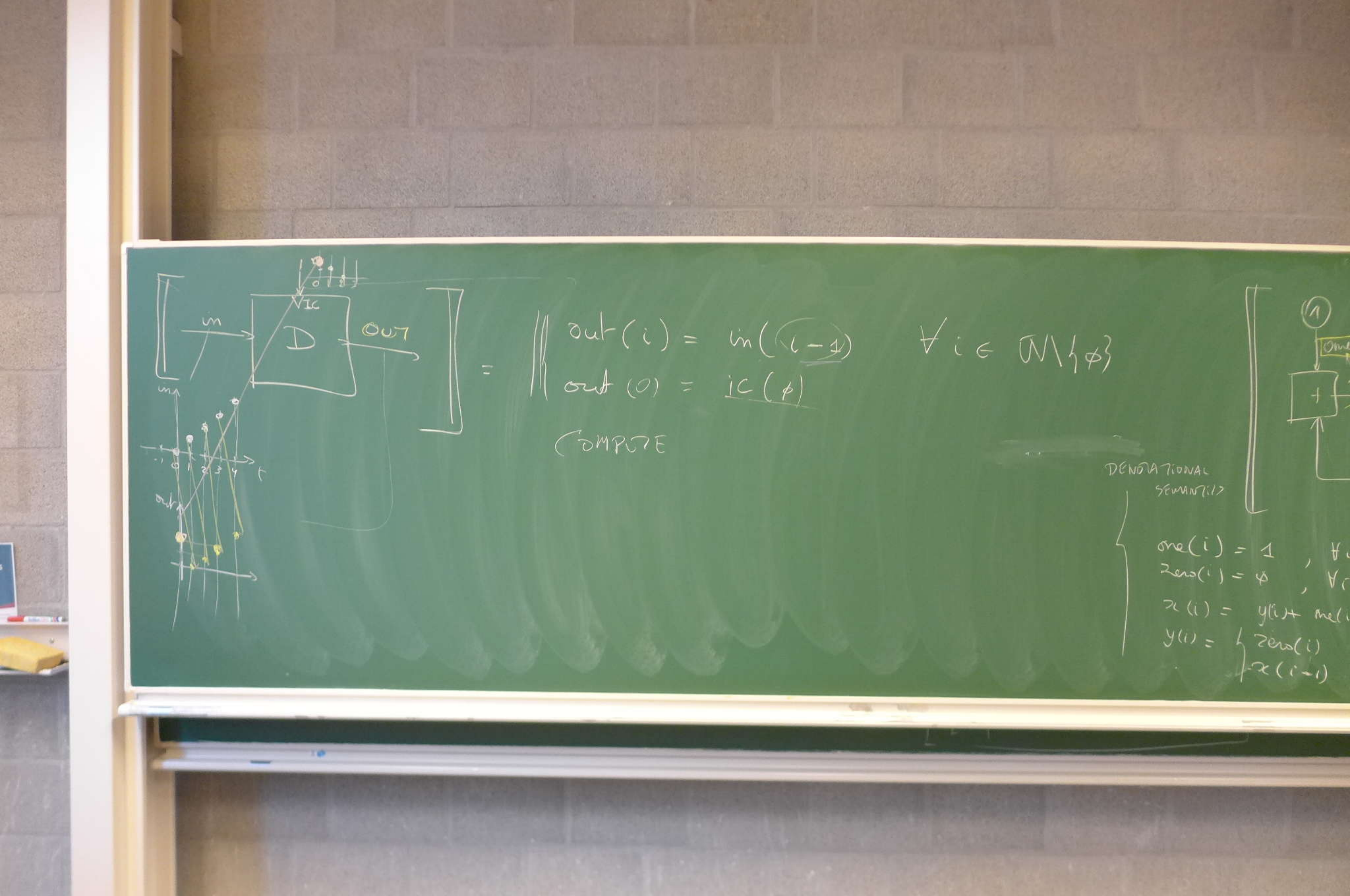
$(x_2, y_2) \longrightarrow \varepsilon_1'' \; \varepsilon_1''$

$\Theta(h^2)$

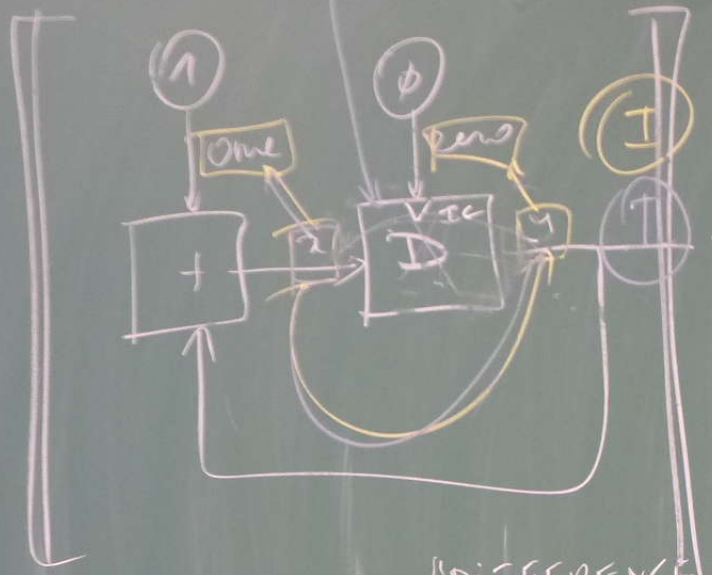
DISCRETE-TIME CBD




A
A(2)
A(1) A(1)
2
1
0 1 2 3 4 5
i ∈ IN


in
IC
D
OUT
out(i) = in(i − 1) ∀ i ∈ N\{0}
out(0) = ic(0)
COMPUTE
DENOTATIONAL SEMANTICS
one(i) = 1
zero(i) = 0
x(i) = y(i) + one(
y(i) = zero(i)
x(i − 1)

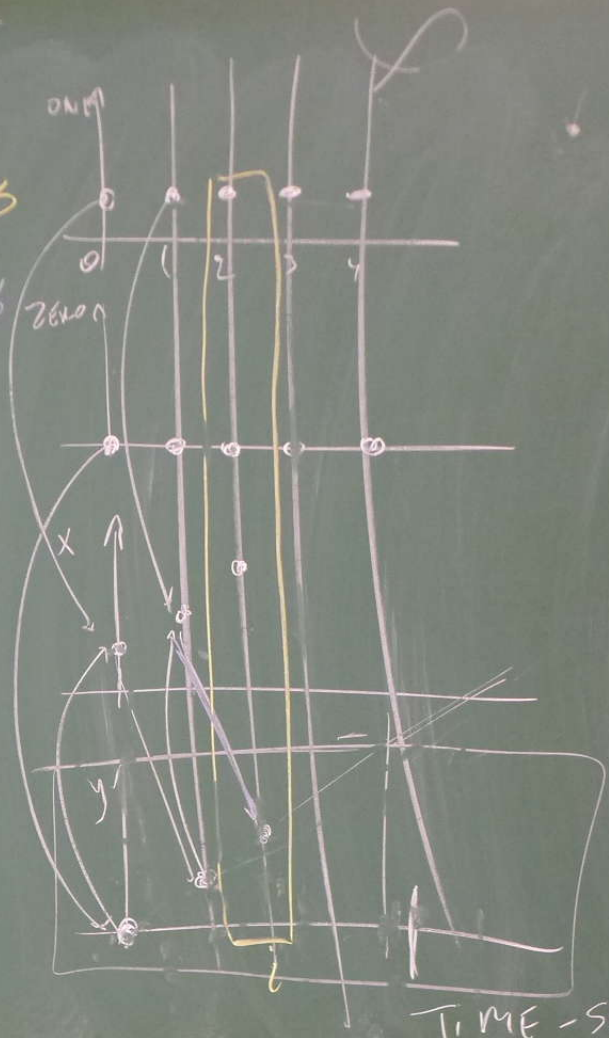
LOOP BREAKER



"DIFFERENCE EQN."

DENOTATIONAL SEMANTICS

$$\begin{cases} one(i) = 1 & , \forall i \in \mathbb{N} \\ zero(i) = 0 & , \forall i \in \mathbb{N} \\ x(i) = y(i) + one(i) & , \forall i \in \mathbb{N} \\ y(i) = \begin{cases} zero(i) & , i = 0 \\ x(i-1) & , i > 0 \end{cases} \end{cases}$$

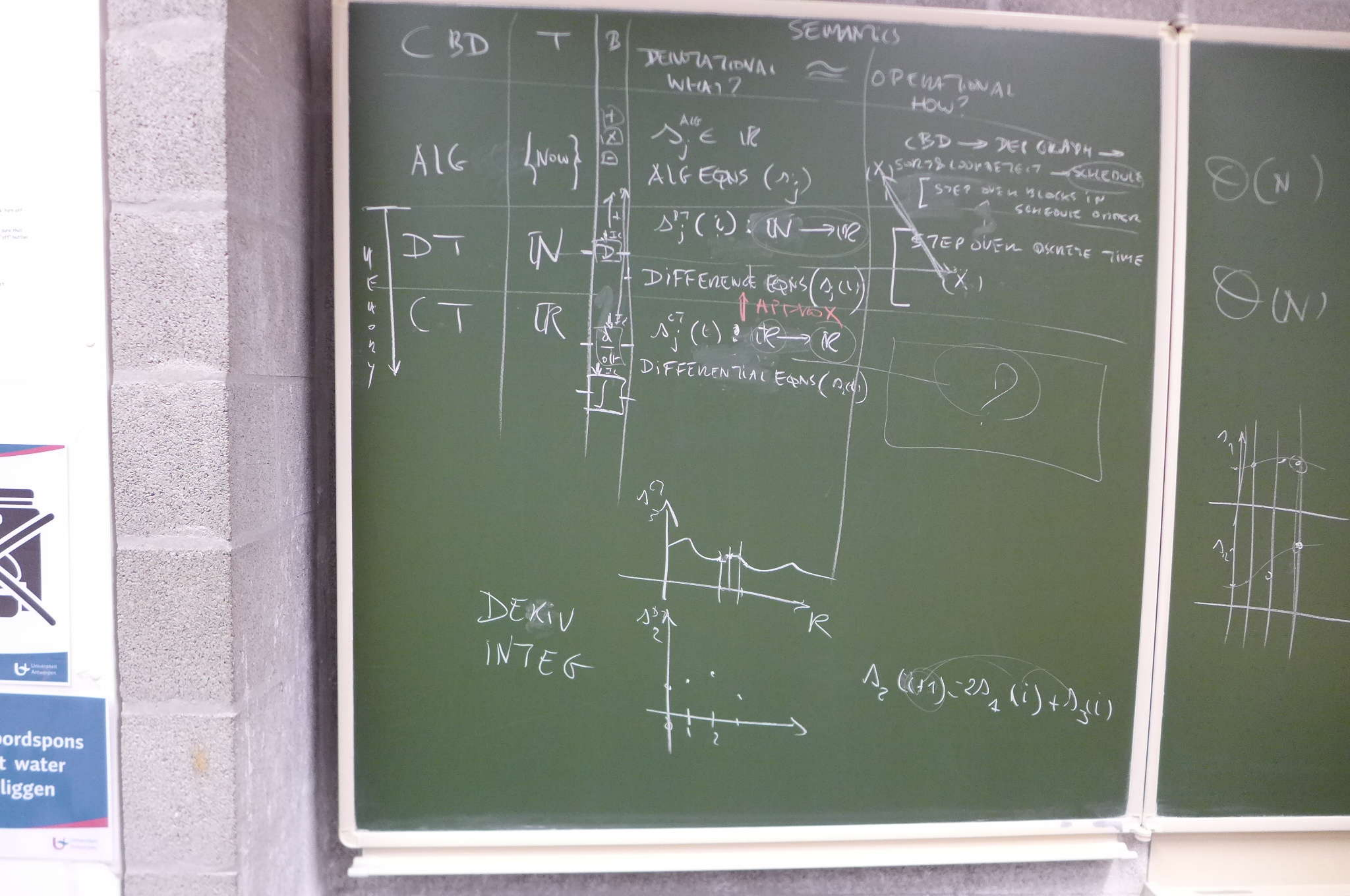


TIME-SLICING

DISCRETE - TIME CBD

```
i = 0
WHILE NOT END_COND(i, EXT):
    DG = DEPGRAPH(CBD)
    S = SCHEDULE(DG)
    FOR GBLOCK IN S:
        GBLOCK.COMPUTE()
    i = i+1
```

```
i = 0
DG = DEPGR(CBD)
S = SCHEDULE(DG)
FOR GBL...
i = 1
DG = DEP
S = SCH
WHILE NOT END
    FOR GBLOCK IN S
        GB COMPUTE()
```


CBD
T
B
SEMANTICS
DENOTATIONAL
WHAT?
OPERATIONAL
HOW?
ALG
{NOW}
ALG EQNS
DT
CT
DIFFERENCE EQNS
APPROX
DIFFERENTIAL EQNS
CBD → DEP GRAPH →
SCHEDULE
STEP OVER BLOCKS IN SCHEDULE ORDER
STEP OVER DISCRETE TIME
DERIV
INTEG
oordspons
t water
liggen

CBD | T | B

SEMANTICS

DENOTATIONAL ≈ OPERATIONAL

WHAT? | HOW?

ALG | {NOW} | $\lambda_j^{ALG} \in \mathbb{R}$

ALG EQNS (λ_j)

CBD → DEP GRAPH → SORT & LOOP DETECT → SCHEDULE

[STEP OVER BLOCKS IN SCHEDULE ORDER]

DT | $\mathbb{N}$ | $\lambda_j^{DT}(i) : \mathbb{N} \to \mathbb{R}$

STEP OVER DISCRETE TIME

DIFFERENCE EQNS $(\lambda_j(i))$

CT | $\mathbb{R}$ | $\lambda_j^{CT}(t) : \mathbb{R} \to \mathbb{R}$

APPROX → ERROR (ACCURACY/PRECISION)

DIFFERENTIAL EQNS $(\lambda_j(t))$

?

$x(t) = \sin(t)$

$\dot{x} = \frac{d}{dt}(-y) = -\frac{dy}{dt} = -\frac{d}{dt}\left(\frac{d}{dt}x\right) = -\frac{d^2}{dt^2}x$

$y = \frac{dx}{dt}$

$x(0) = 0$

$\frac{dx}{dt}(0) = 1$

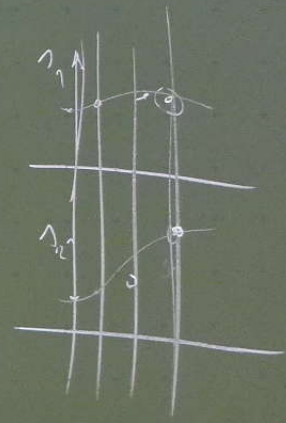
$x(t) = A\sin(t) + B\cos(t) \quad // \quad 0$

$\frac{dx}{dt} = A\cos(t) - B\sin(t)$

$\frac{d^2x}{dt^2} = -(A\sin(t) + B\cos(t))$

$\mathcal{O}(N)$

$\mathcal{O}(N) \times \mathcal{O}$



$\mathcal{O}(N)$

$\mathcal{O}(N) \times \mathcal{O}(T)$

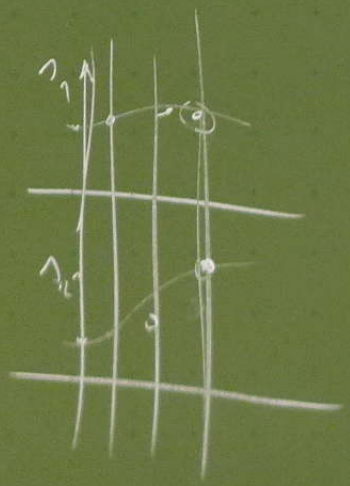
$\frac{dx(t)}{dt} = x(t)$ | $x(0) = 1$

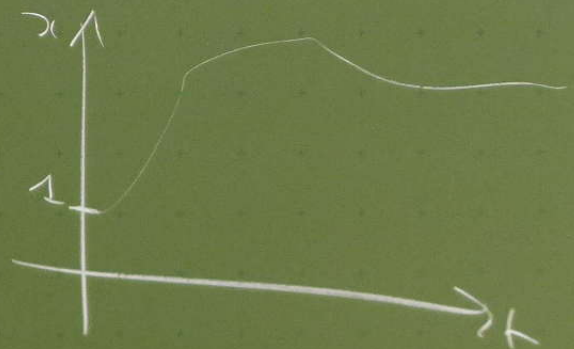
$x(t) \cdot \frac{t^2}{2} + 1$

$\frac{d}{dt} \cdot 1 = t$

$x(t) \cdot e^t$

$\frac{d\,x(t)}{dt} : e^t$





$\frac{d\,t^2}{dt} : 2t$

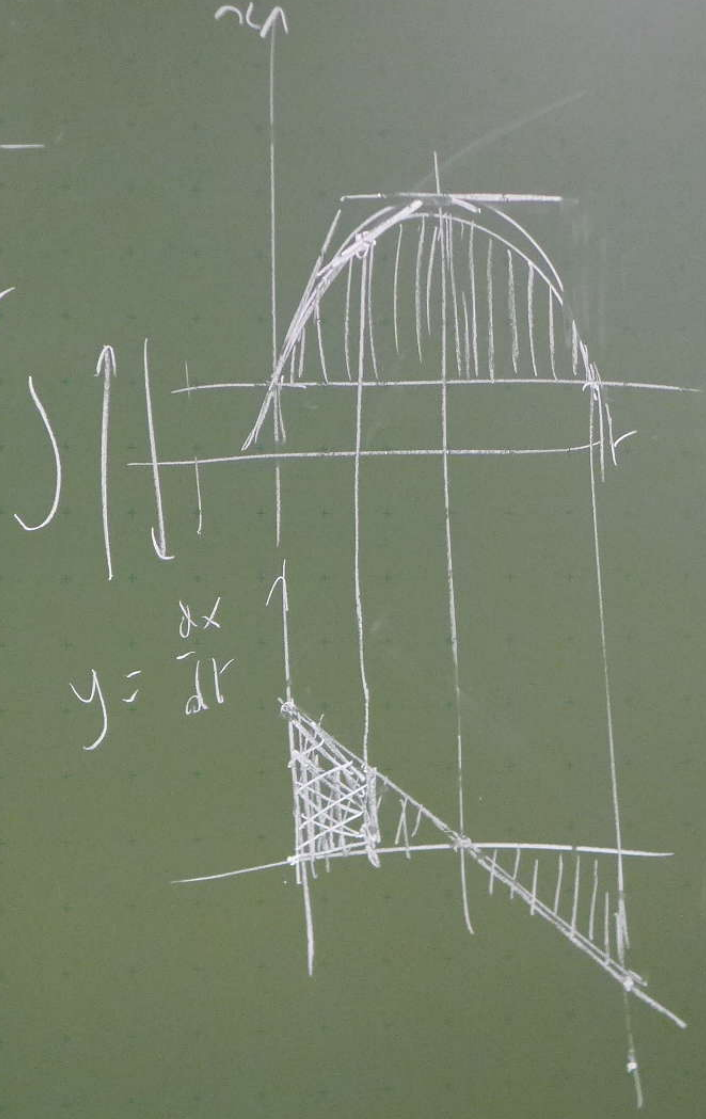
$x(t)$ $\frac{t^2}{2} + 1$

(t)

$\frac{d}{dt}$ $= t$

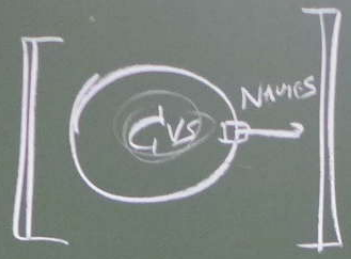
$x(t) \cdot e^t$

$\frac{d[x(t) \cdot e^t]}{dt} = e^t$



$P(t) = e^t$

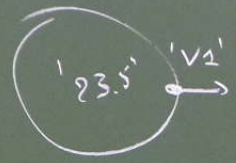
C7-CBD DENOTATIONAL SEMANTICS



::=

VAR(NAMES)(t) = VAL(CVS)

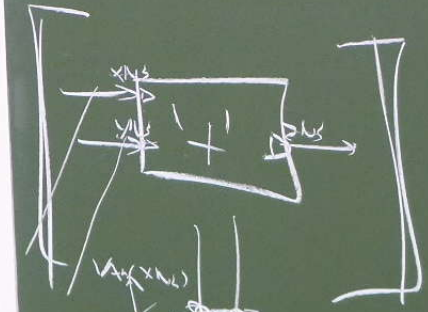
∀ t ∈ TR



VAR('V1')

V1 : TR → R

t 23.5



::=

VAR(ZNS)(t) = VAR(XNS)(t) VAR(YNS)(t)

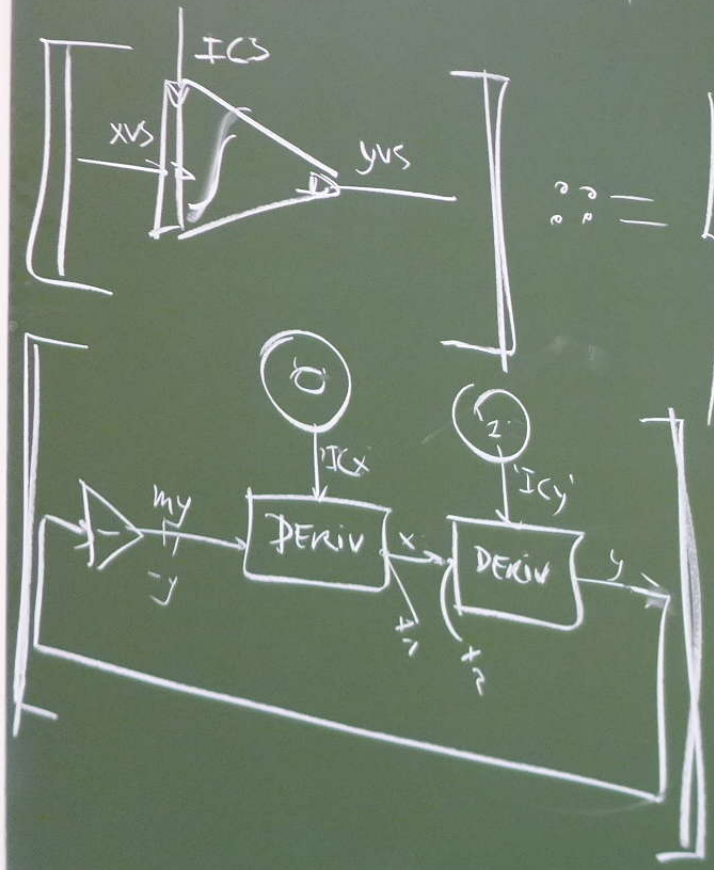
∀ t ∈ TR

$::=$

$VAR(yvs)(\phi) = VAR(ics)(0)$

$VAR(yvs)(t) = \frac{d}{dt} VAR(xvs)$

$\forall t \in \mathbb{R} \quad t > 0$



$::=$

$VAR(yvs)(\phi) = VAR(ics)(0)$

$VAR(yvs)(t) = \int_0^t VAR(xvs)(\tau)\,d\tau$

$t > 0 \quad t \in \mathbb{R}$

$::=$

$my(t) = -y(t)$

$ICx(t) = 4$

$ICy(t) = 2$

$y(0) = ICy(0)$

$x(0) = ICx(0)$

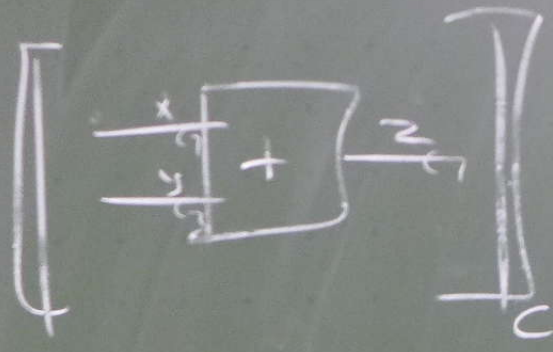
$y(t) = \frac{dy}{dt}$

$x(t) = \frac{d\,my}{dt}$

SEMANTICS

CBD	T	B	DENOTATIONAL WHAT?	≈	OPERATIONAL HOW?
ALG	{NOW}	+ × D	$\Lambda_j^{ALG} \in \mathbb{R}$ ALG EQNS (Λ_j)		CBD → DEP GRAPH → SORT & LOOP DETECT → SCHEDULE [STEP OVER BLOCKS IN SCHEDULE ORDER
DT	ℕ	D	$\Lambda_j^{DT}(i) : \mathbb{N} \to \mathbb{R}$ DIFFERENCE EQNS $(\Lambda_j(i))$		STEP OVER DISCRETE TIME
CT	ℝ	∫	$\Lambda_j^{CT}(t) : \mathbb{R} \to \mathbb{R}$ DIFFERENTIAL EQNS $(\Lambda_j(t))$	APPROX →	ERROR (ACCURACY/PRECISION)

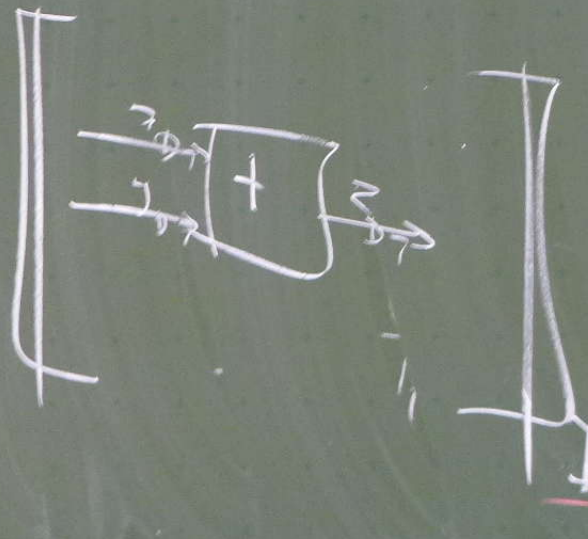
MEMORY



$:=$ $z(t) = x(t) + y(t)$, $\forall t \in \mathbb{R}$

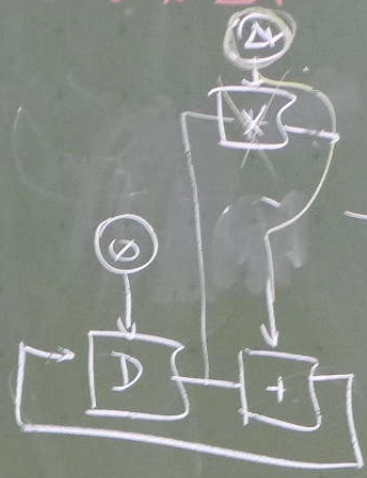
approx

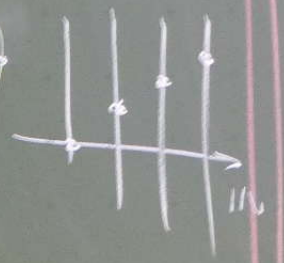
Disc



$:=$ $z(i) = x(i) + y(i)$, $\forall i \in \mathbb{N}$

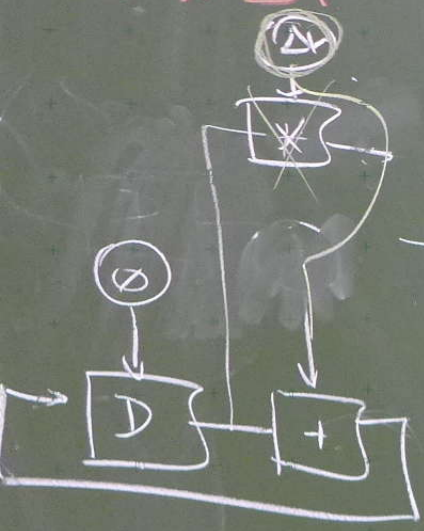
$t = i * \Delta t$



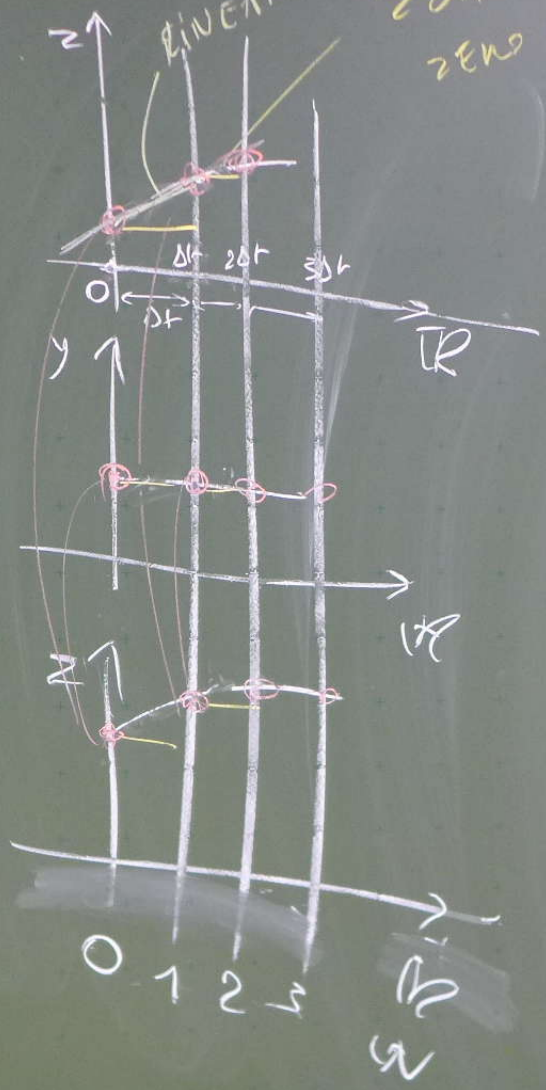


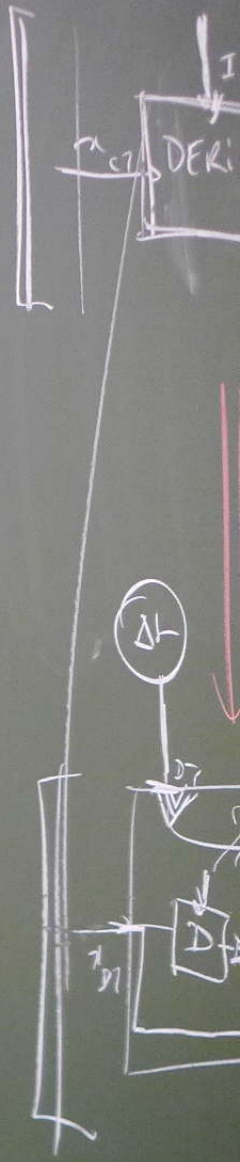
$x(t) + y(t)$, $\forall t \in \mathbb{R}$

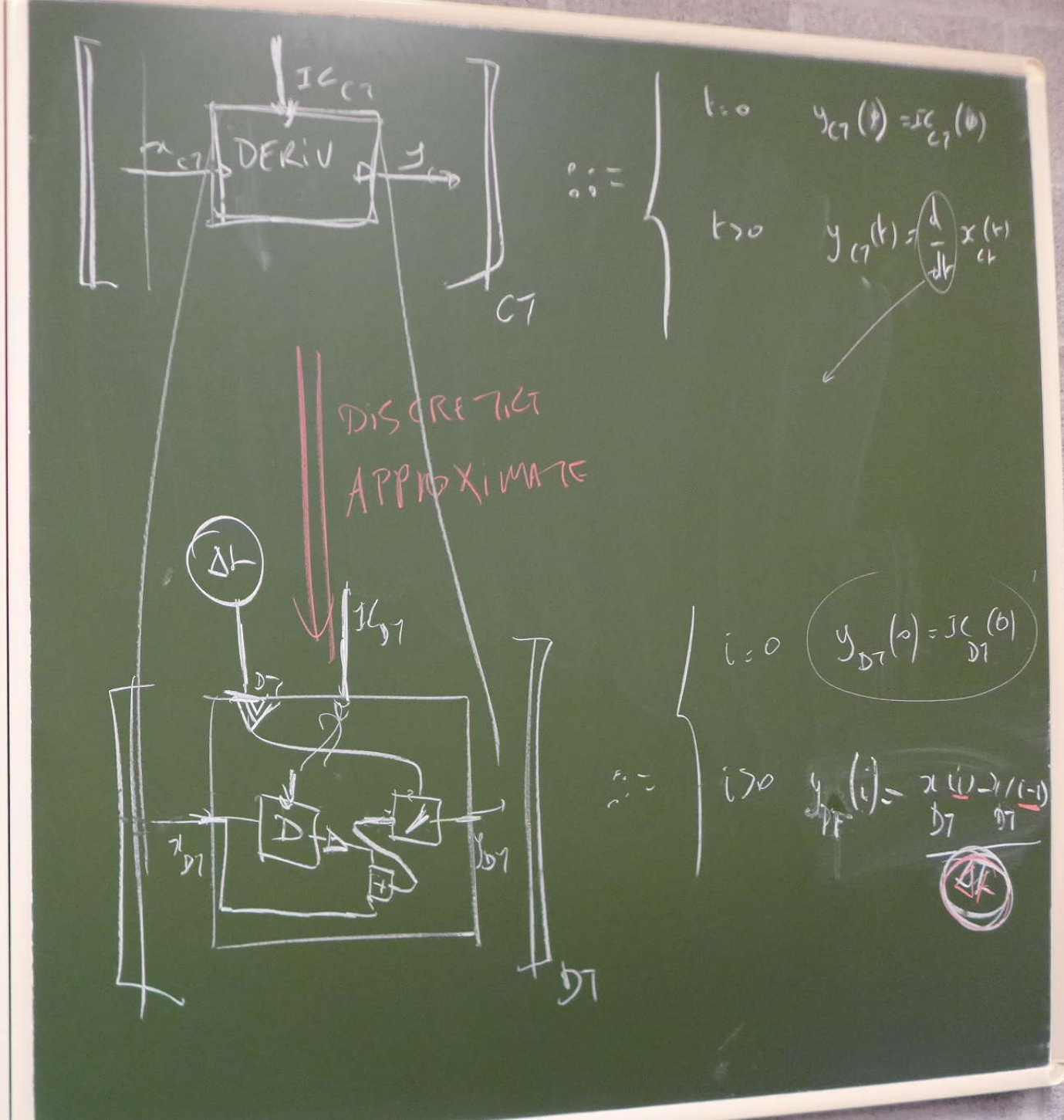
$= i * \Delta t$

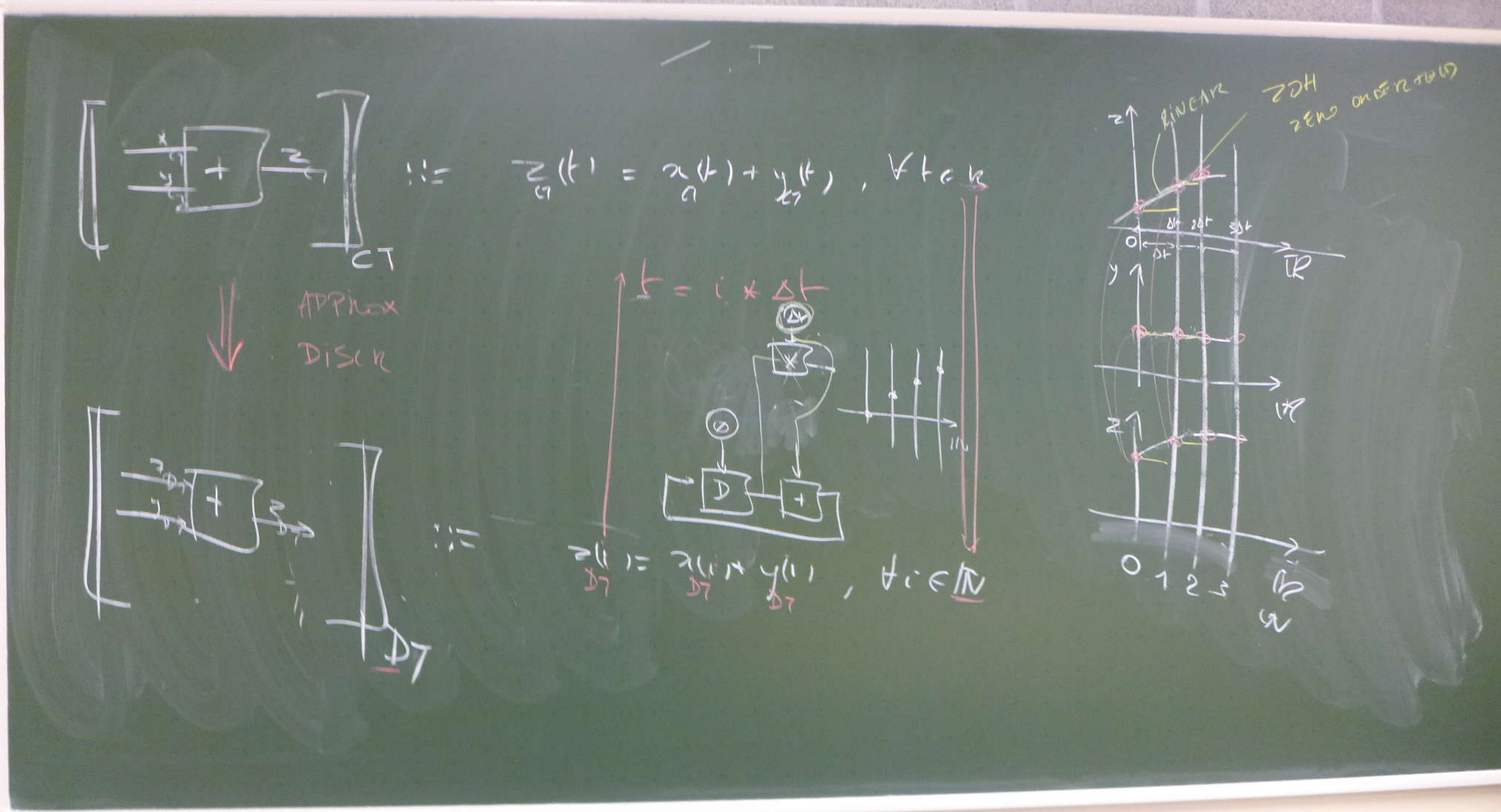


$x(i \cdot \Delta t) + y(i \cdot \Delta t)$, $\forall i \in \mathbb{N}$

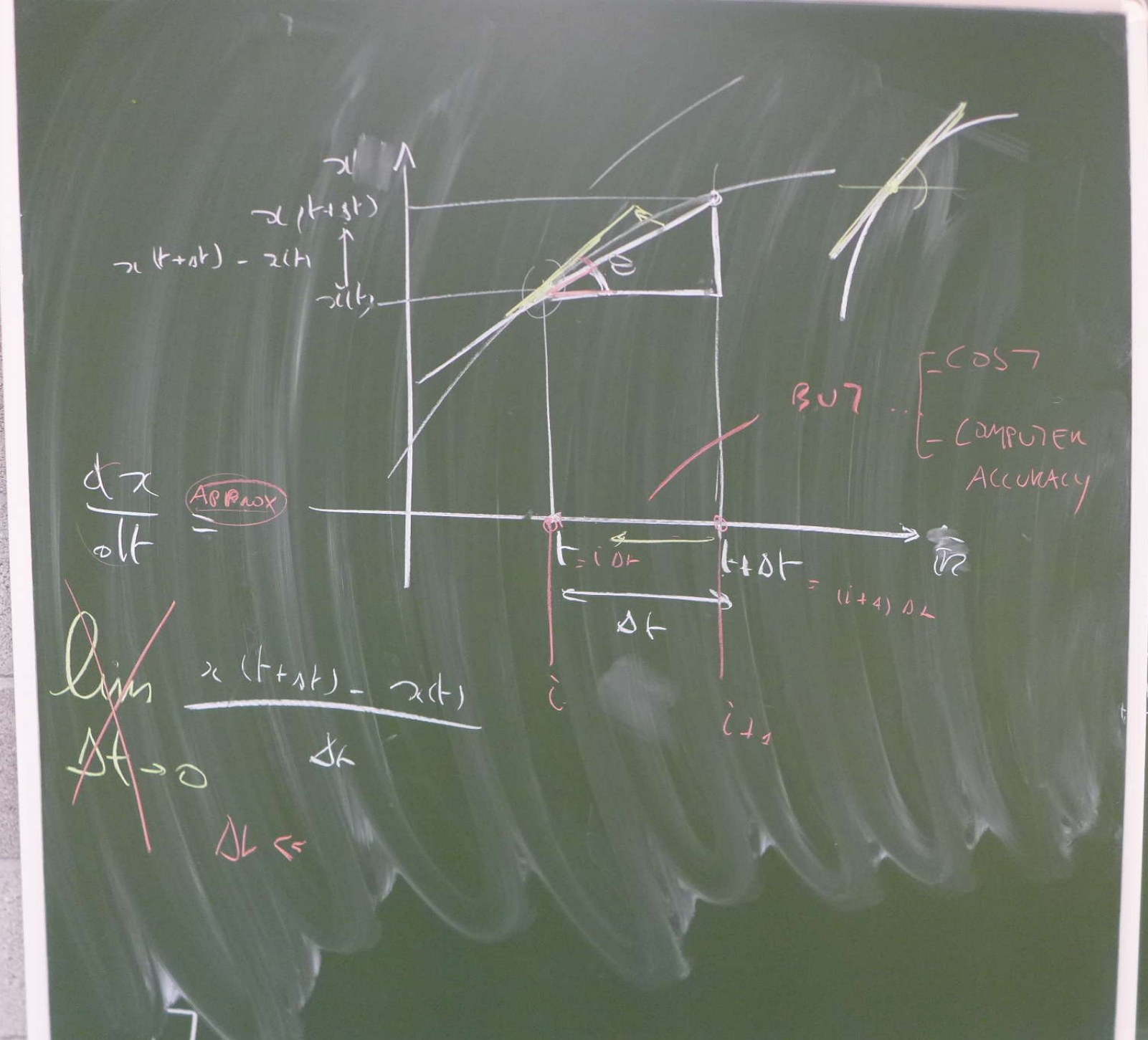


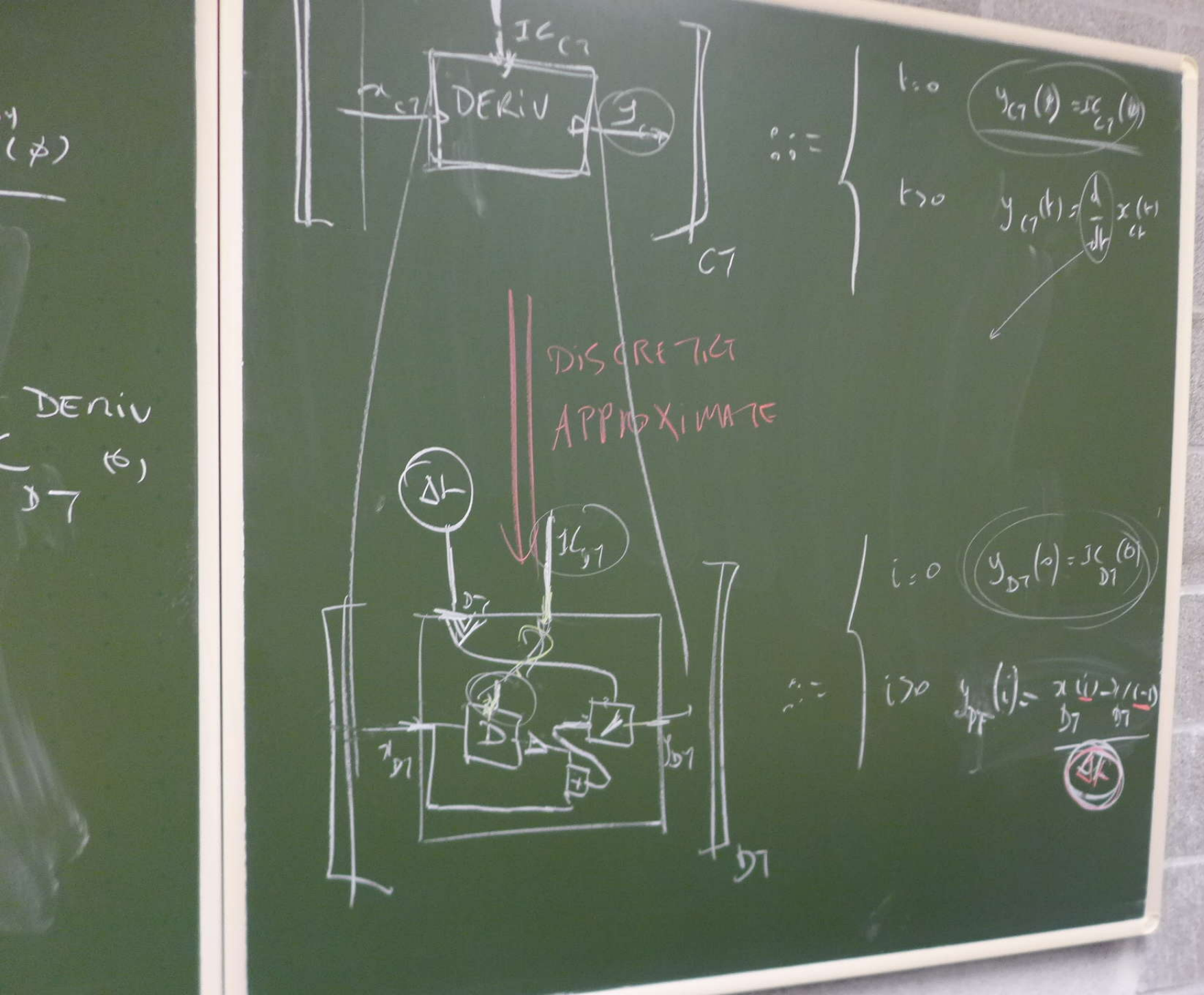



DERIV
DISCRETIZE
APPROXIMATE



CT
APPROX
DISCR
DT
::=
z_CT(t) = x_CT(t) + y_CT(t), ∀t ∈ ℝ
t = i * Δt
z_DT(i) := x_DT(i) + y_DT(i), ∀i ∈ ℕ
LINEAR
ZOH
ZERO ORDER HOLD
Δt 2Δt 3Δt
0 1 2 3


x
x(t+Δt)
x(t+Δt) - x(t)
x(t)
ε
t = i Δt
t+Δt = (i+1) Δt
Δt
i
i+1
BUT ..
- COST
- COMPUTER ACCURACY
dx/dt ≈ APPROX
lim Δt→0
x(t+Δt) - x(t) / Δt
Δt ≤
∀ i ∈ ℕ


DERIV
CT
DISCRETIZE
APPROXIMATE
DT
t = 0
t > 0
i = 0
i > 0

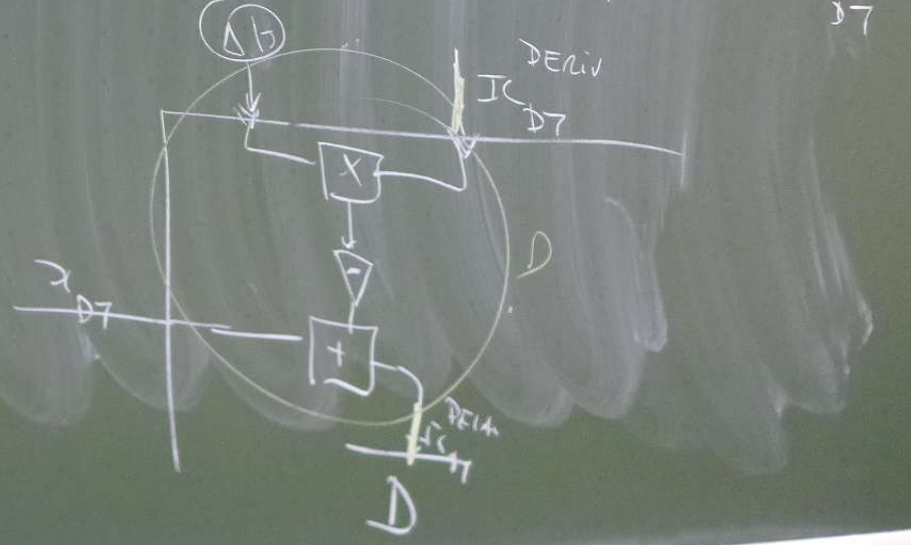
$$y_{DT}(0) = IC_{DT}^{DERIV}(\phi)$$

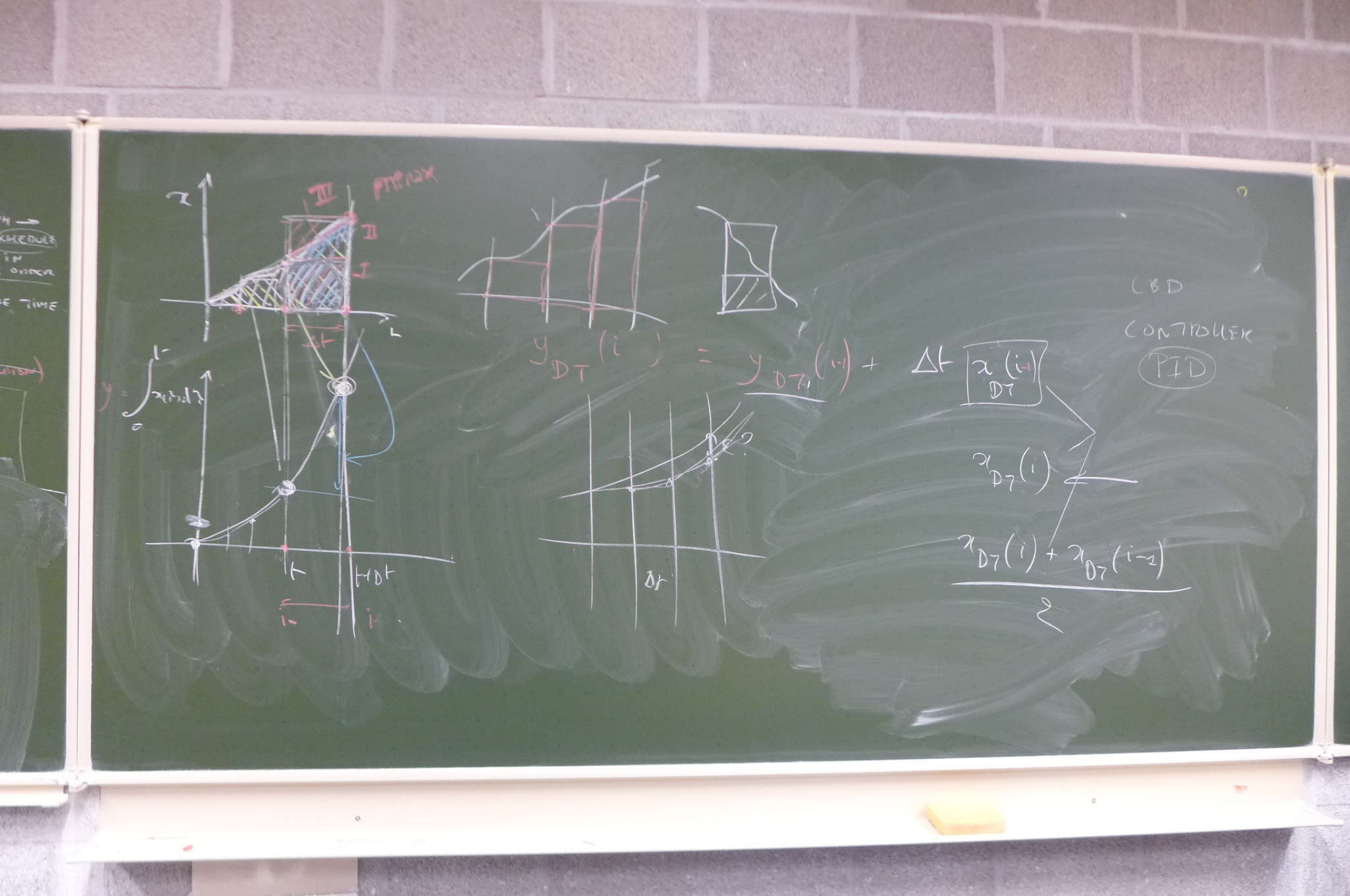
$$\| $$

$$y_{DT}(0) = \frac{x_{DT}(0) - \overbrace{DELAY(x, 0)}^{IC_{DT}^{DELAY}(0)}}{\Delta t}$$

$$IC_{DT}^{DERIV}(\phi) = \frac{x_{DT}(\phi) - IC_{DT}^{DELAY}(\phi)}{\Delta t}$$

$$IC_{DT}^{DELAY}(\phi) = x_{DT}(\phi) - \Delta t \times IC_{DT}^{DERIV}(\phi)$$



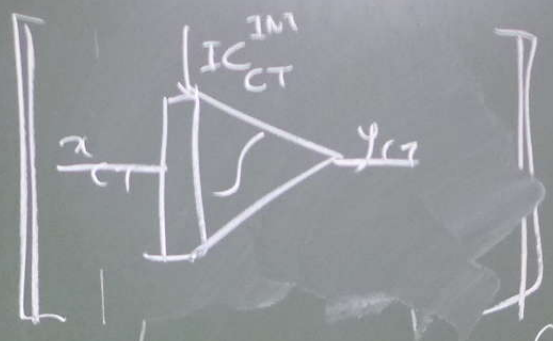

III
II
I
$y = \int_0^t x(\tau)\,d\tau$
$y_{DT}(i) = y_{DT}(i-1) + \Delta t \left[x_{DT}(i-1) \right]$
$x_{DT}(i)$
$x_{DT}(i) + x_{DT}(i-1)$
2
CBD
CONTROLLER
PID

CBD

CONTROLLER

PID

$+ x_{DT}(i-1)$



$:=$

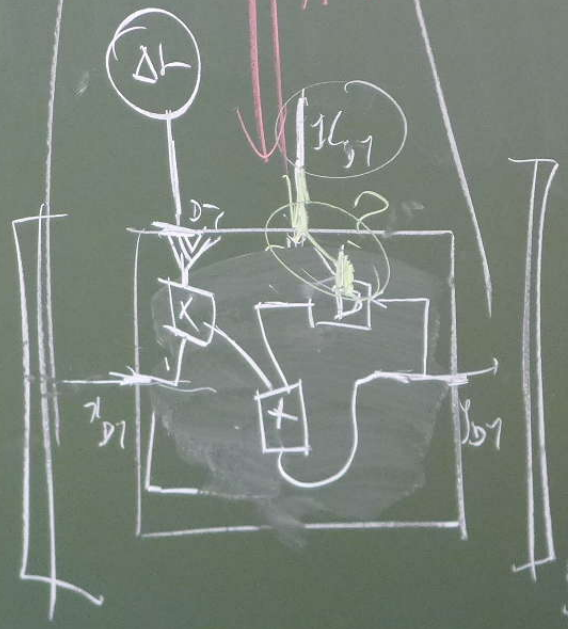
$t=0 \quad y_{CT}(t) = IC_{CT}(0)$

$t>0 \quad y_{CT}(t) = \int_0^t x_{CT}(\tau)\,d\tau$

DISCRETIZE

APPROXIMATE

$\Delta t \ll$

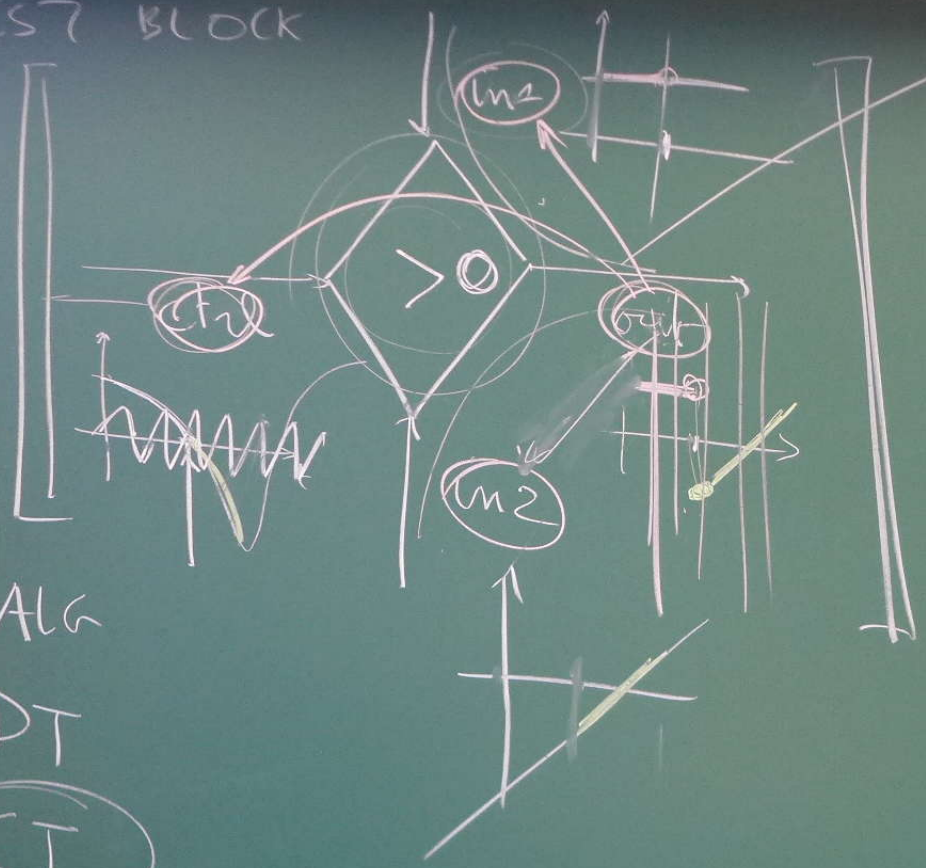


$:=$

$i=0 \quad y_{DT}(0) = IC_{DT}^{IM}(0)$

$i>0 \quad y_{DT}(i) = y_{DT}(i-1) + \Delta t\, x(i)$

TEST BLOCK



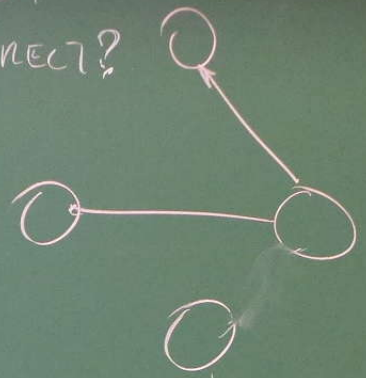
ALG

DT

CT

- FAST
- CONNECT?

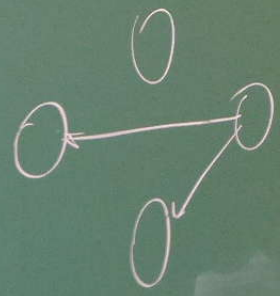
::

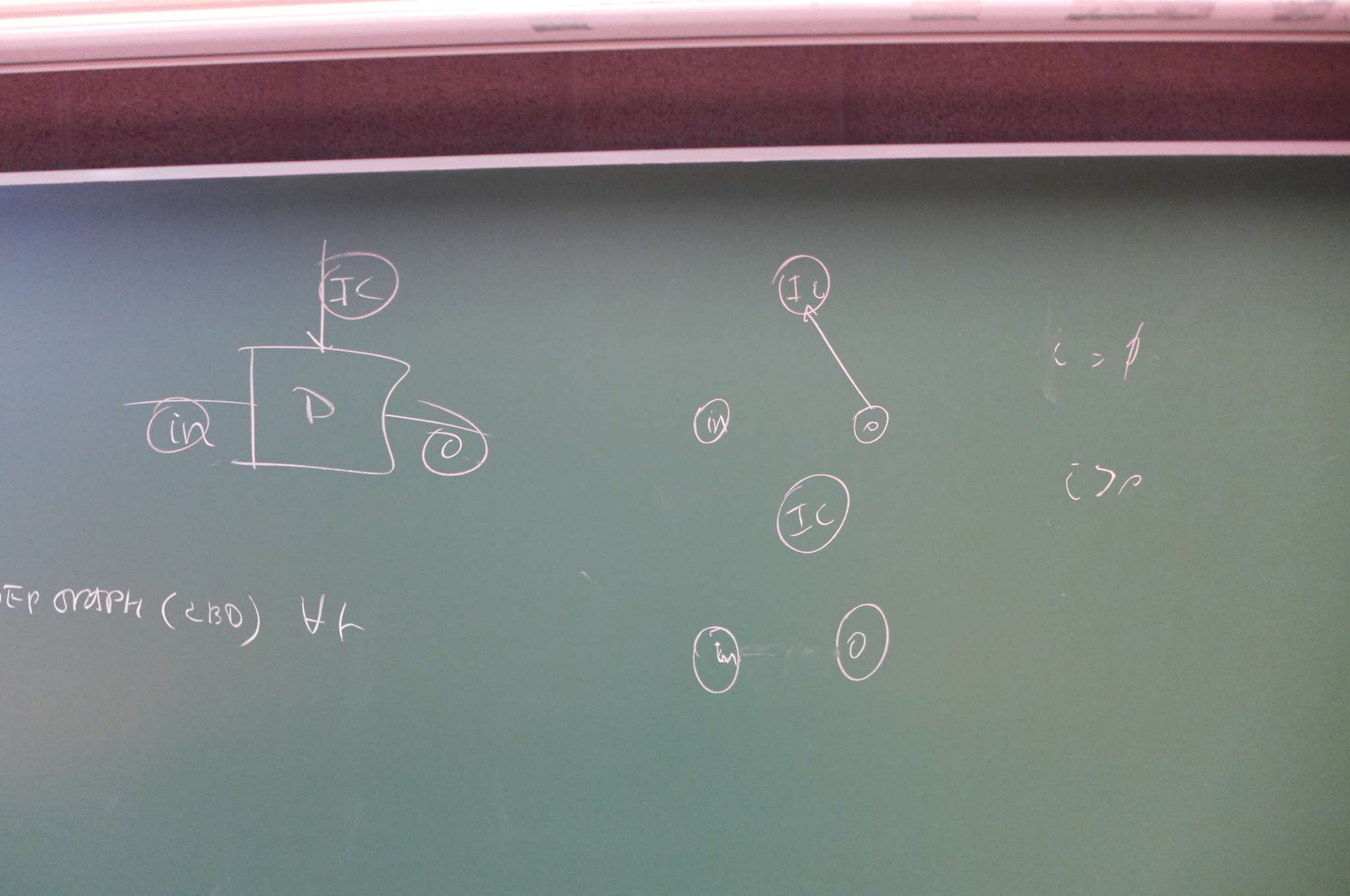


$\forall t \in \mathbb{R}$

- SLOW
- CONNECT

— DEP GRAPH





IC
P
in
o
EP GRAPH (CBD)

i = 0

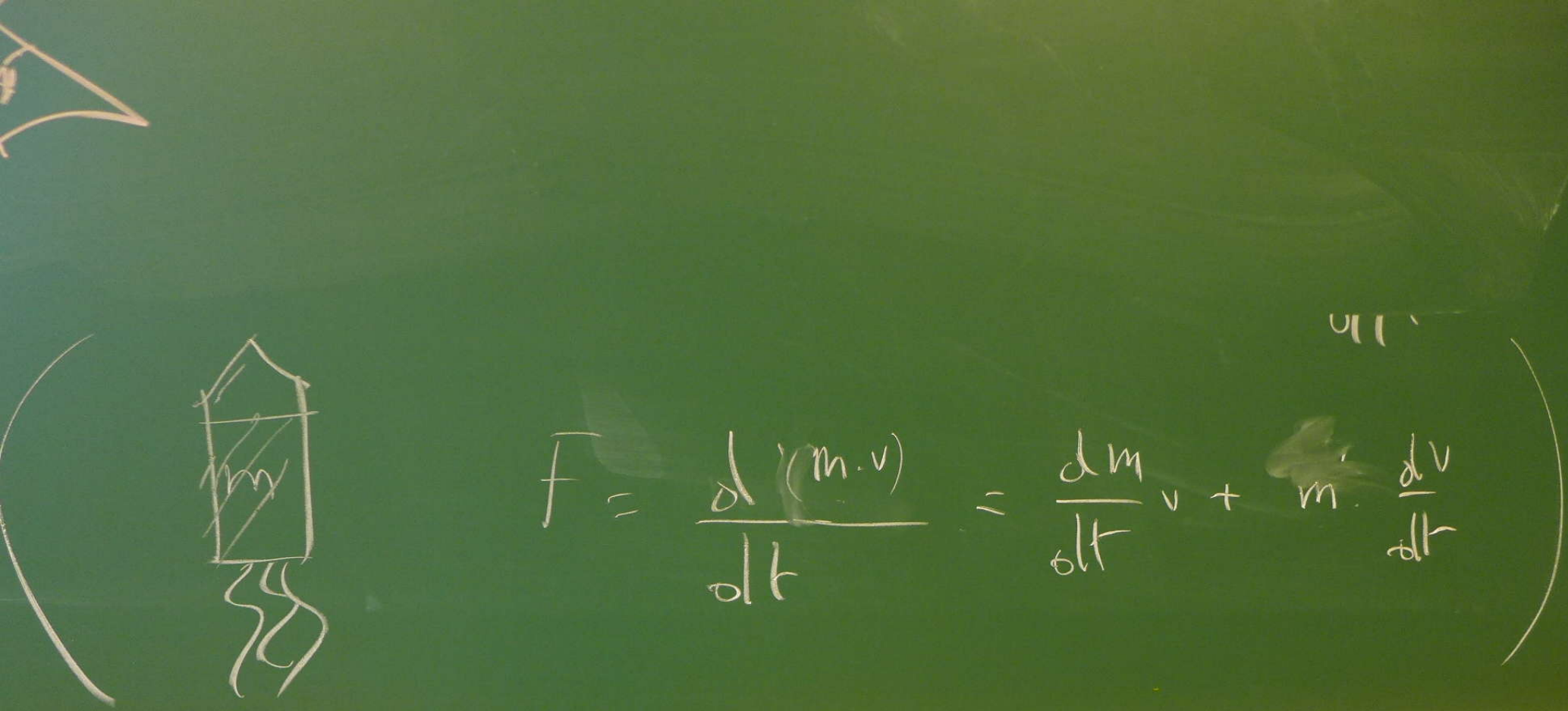
WHILE NOT TERM COND

CBD ⟶ DEPGRAPH → SCHEDULE

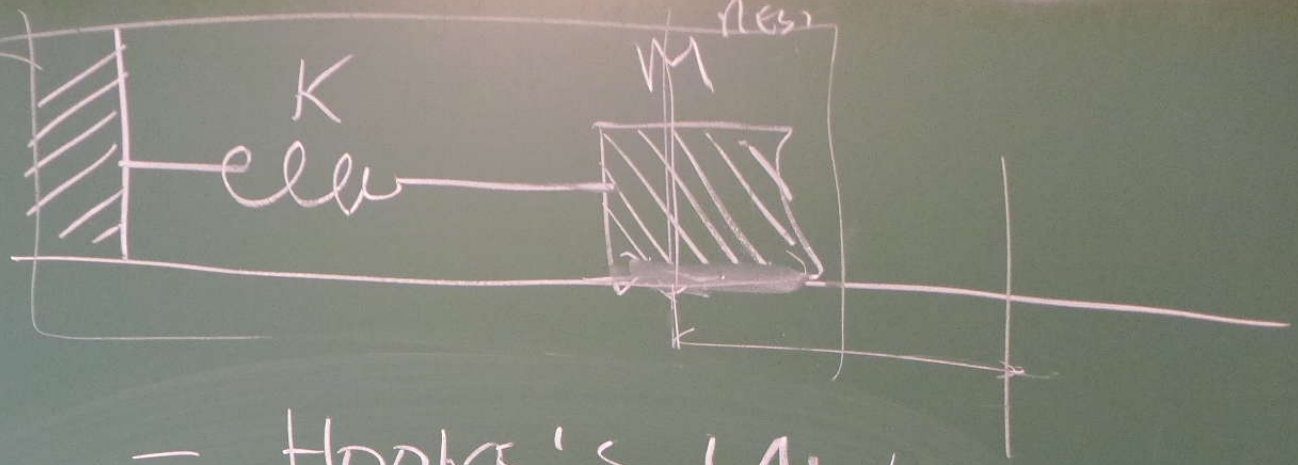
FOR GBLOCK IN SCHED

GBLOCK.COMPUTE

i += 1


m
$F = \frac{d(m \cdot v)}{dt} = \frac{dm}{dt} v + m \cdot \frac{dv}{dt}$

HARMONIC OSCILLATOR



- HOOKE'S LAW
- NEWTON'S LAW

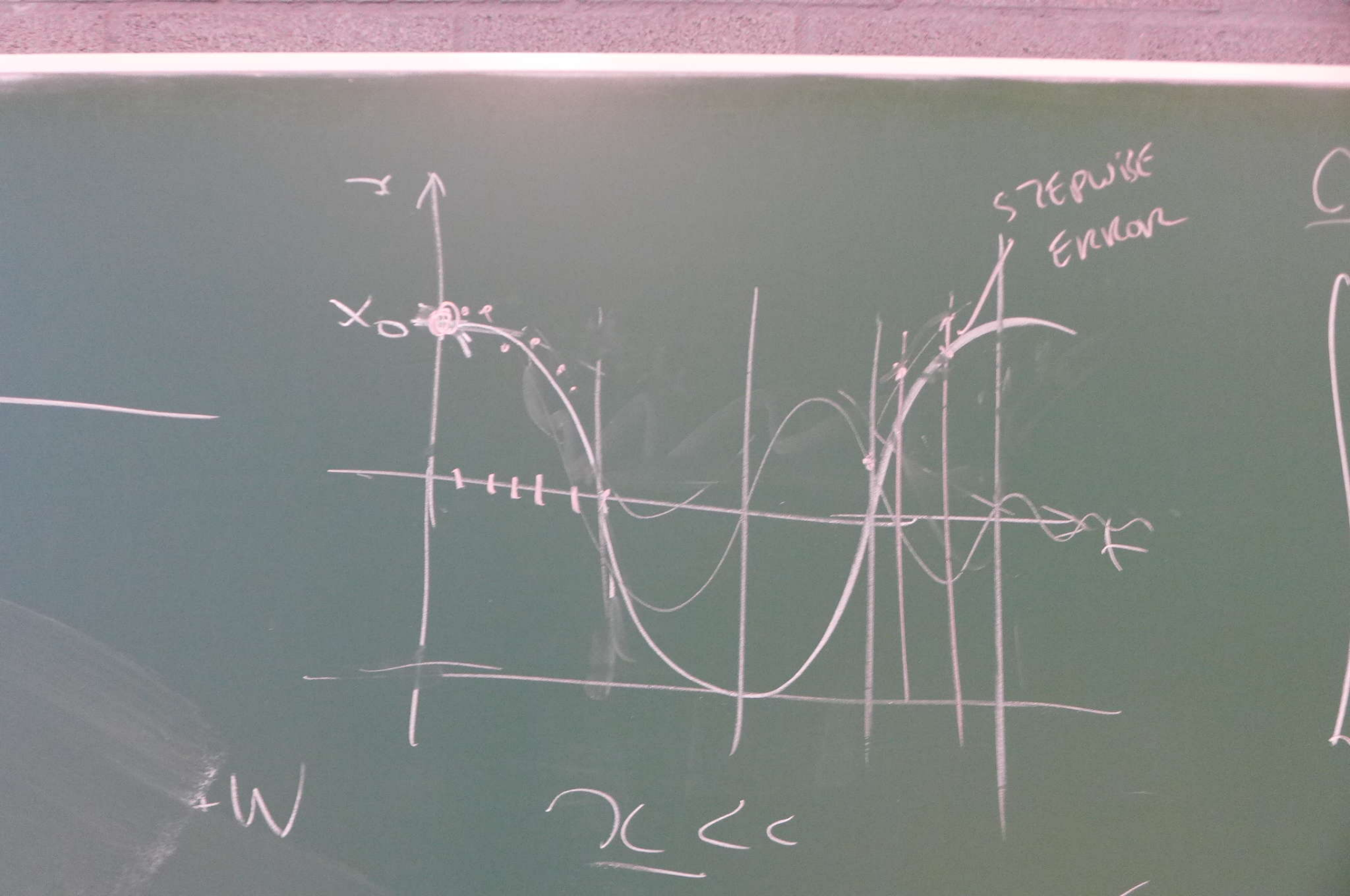
FRANÇOIS CELLIER

SYNCHRONOUS DATA FLOW (SDF)

$x << c$

$$\begin{cases} \dfrac{d^2x}{dt^2} = -\dfrac{k}{m}x \\ x(0) = x_0 \\ \dfrac{dx}{dt}(0) = v_0 \end{cases}$$

$x(t) = A\sin(t) + B\cos t)$


Y
X_0
STEPWISE
ERROR

C7-CSD ENCODE

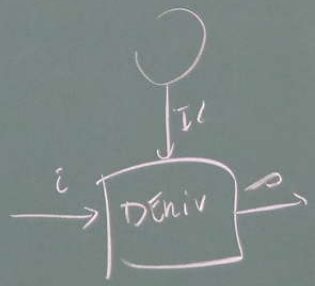
FIRST ORDER ODE

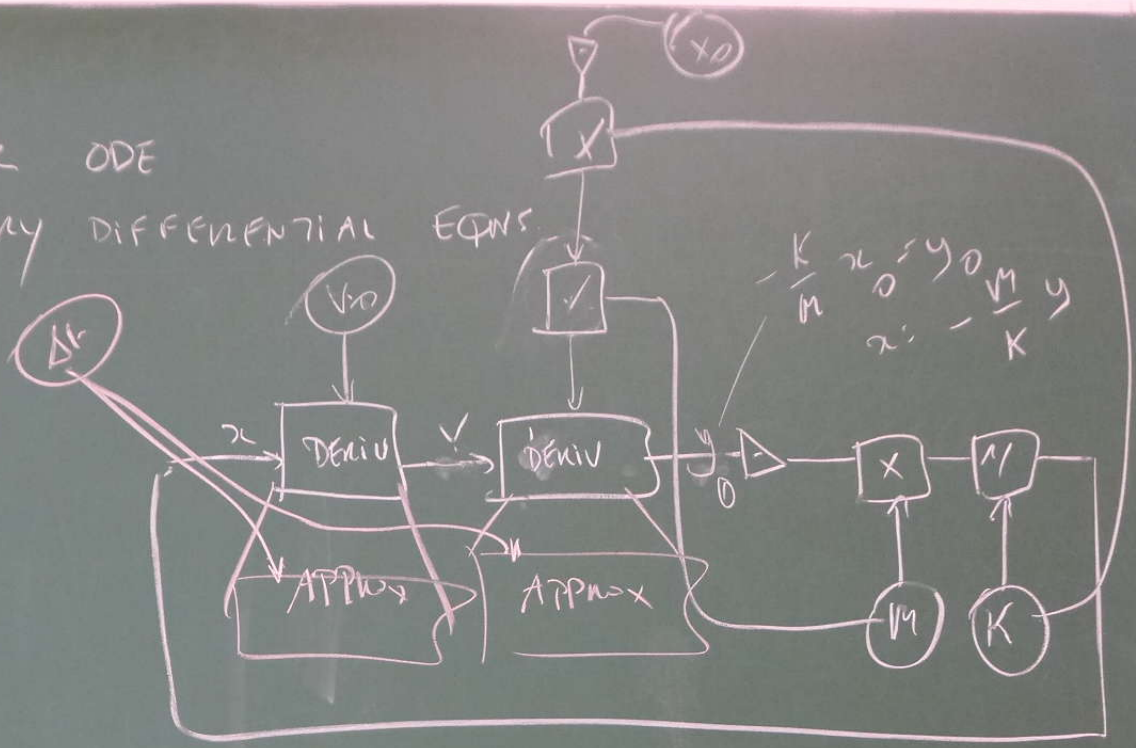
$\frac{dx}{dt} = v \quad \rightleftarrows \quad x = \int v\,dt$ ORDINARY DIFFERENTIAL EQNS

$\frac{dv}{dt} = -\frac{K}{M}x$

$x(0) = x_0$

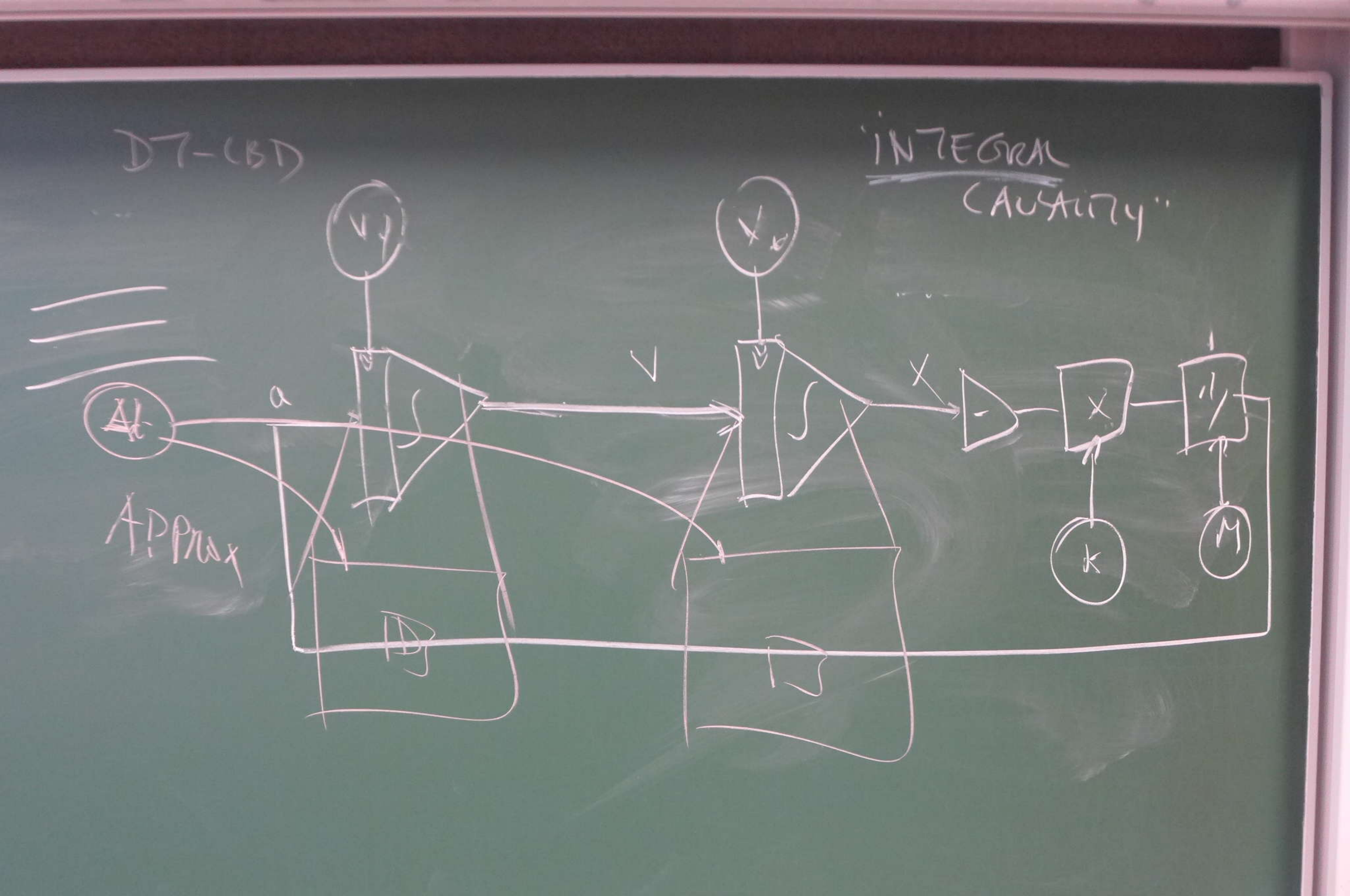
$v(0) = v_0$



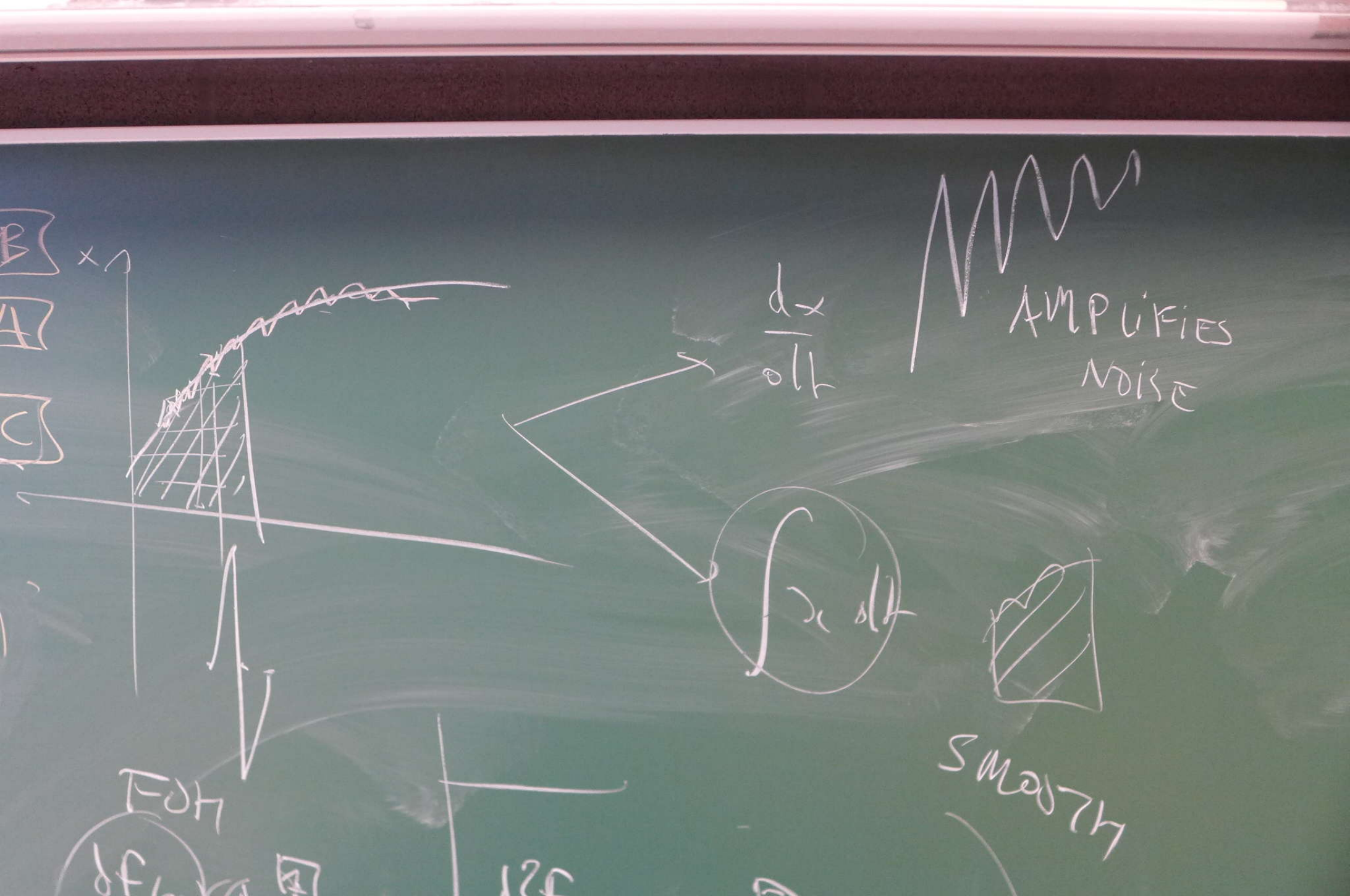


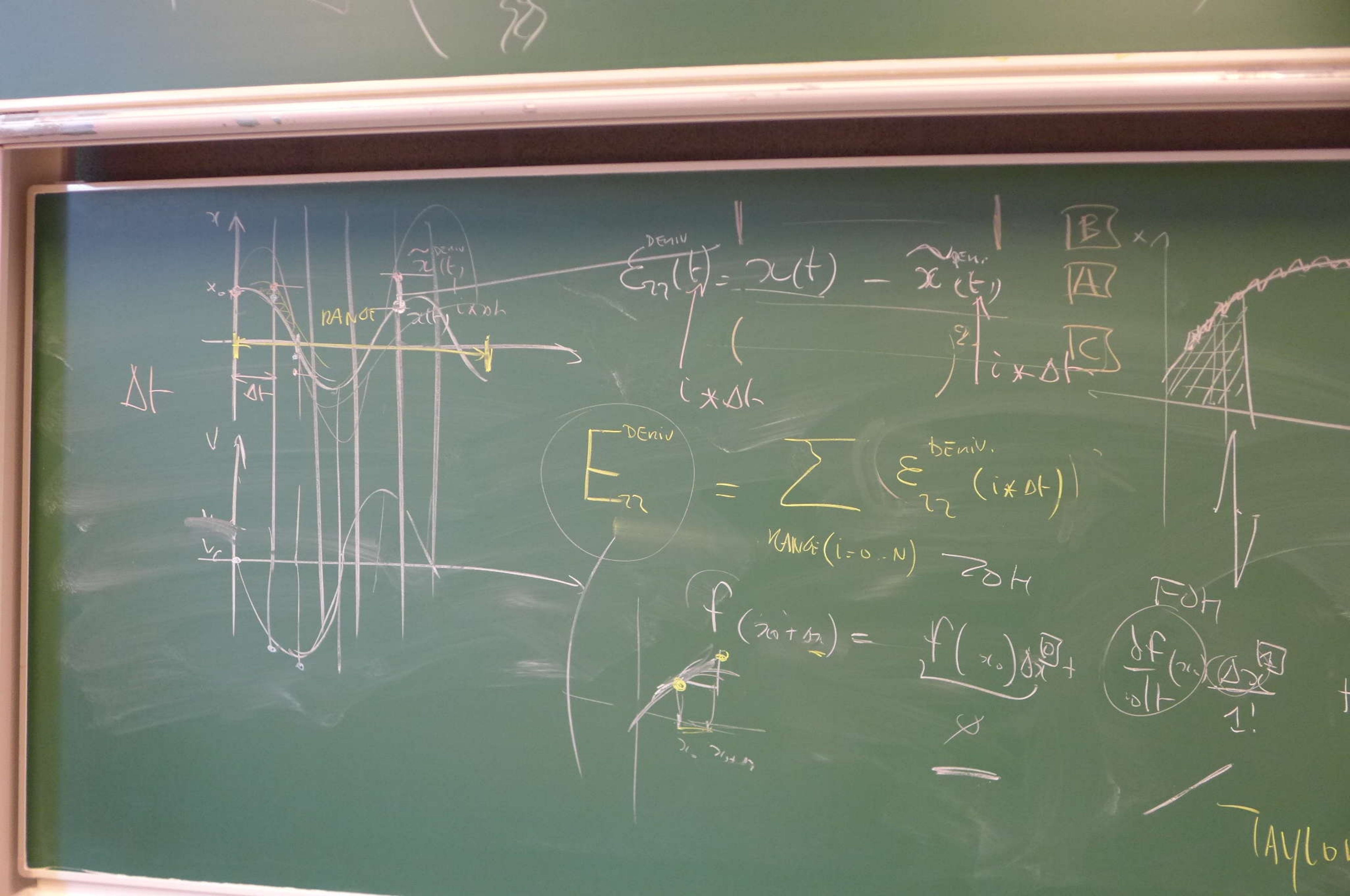
D7-CSD

DERIVATIVE CAUSALITY



DT-CBD
"INTEGRAL CAUSALITY"
APProx
a
v
x
K
M


B
A
C
x
dx
dt
AMPLIFIES
NOISE
SMOOTH


RANGE
Δt
DERIV
i*Δt
ZOH
FOH
RANGE (i=0..N)
TAYLO

DERIV

$\varepsilon_{zz}(t) = x(t) - \tilde{x}(t)$

$i * \Delta t$

$i * \Delta t$

B

A

C

$\frac{dx}{dt}$

AMPLIFIES NOISE

$E_{zz}^{DERIV} = \sum \varepsilon_{zz}^{DERIV.}(i * \Delta t)$

RANGE $(i = 0 \ldots N)$

ZOH

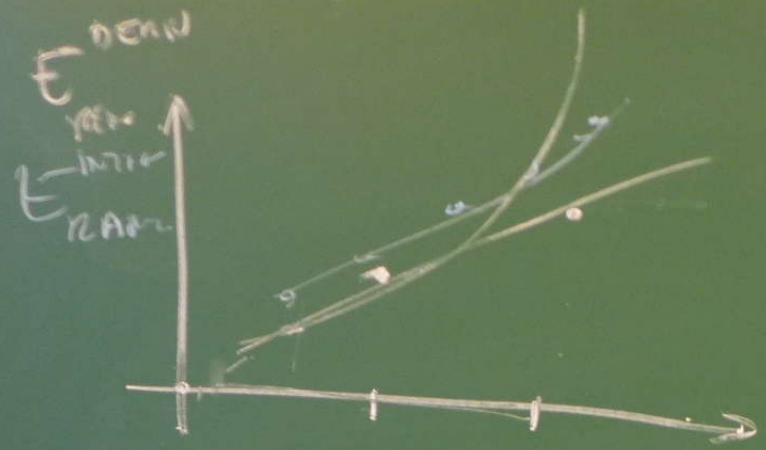
FOH

$\int x \, dt$

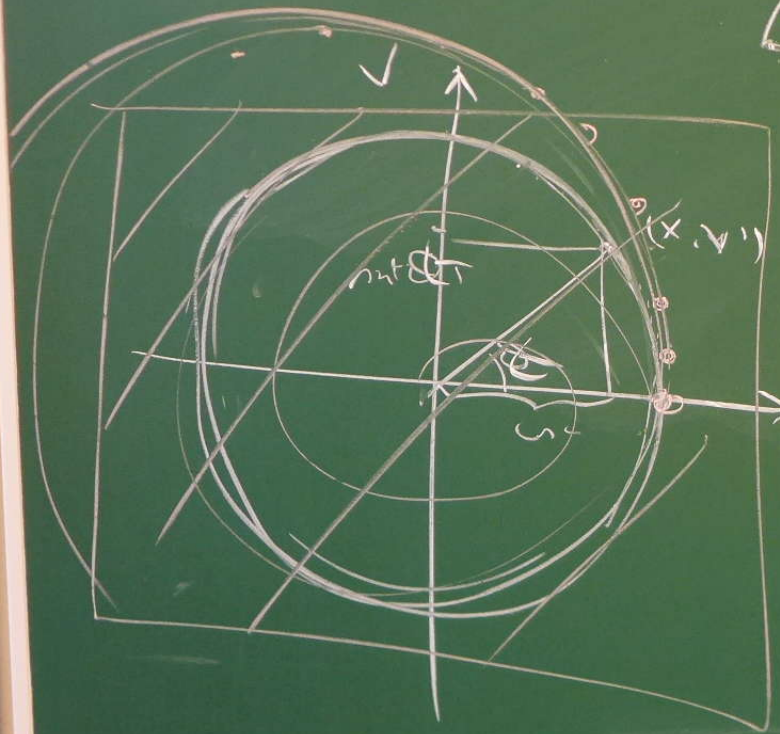
SMOOTH

$f(x_i + \Delta x) = f(x_i) + \frac{df}{dt}(x_i)\frac{\Delta x}{1!} + \frac{d^2 f}{dt^2}(x_i)\frac{\Delta x^2}{2!} + \cdots$

TAYLOR EXPANSION



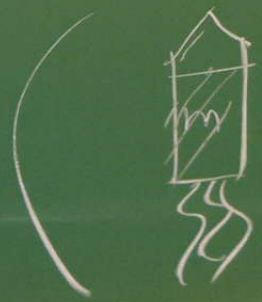
HARMONIC OSCILLATOR



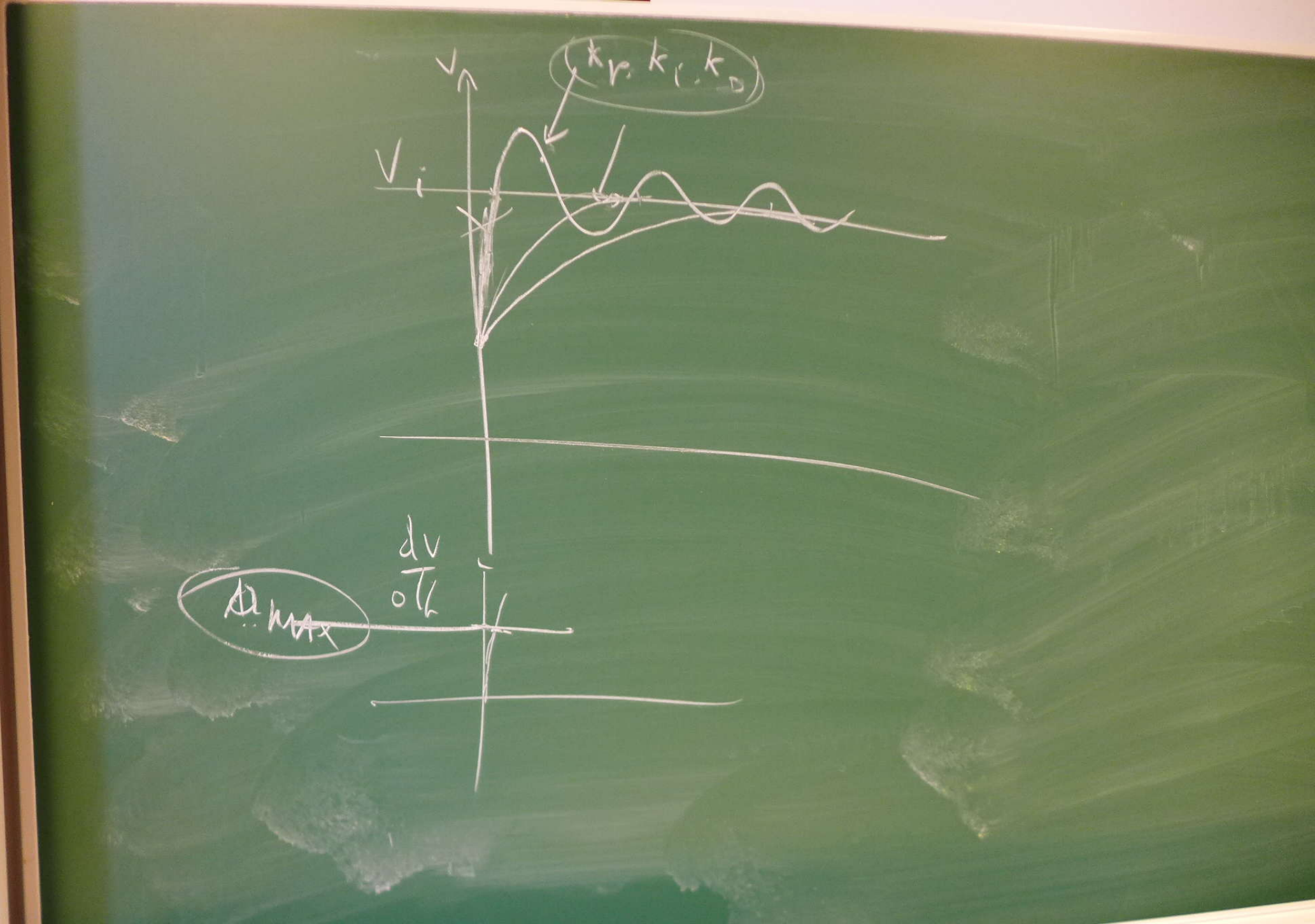
STABLE

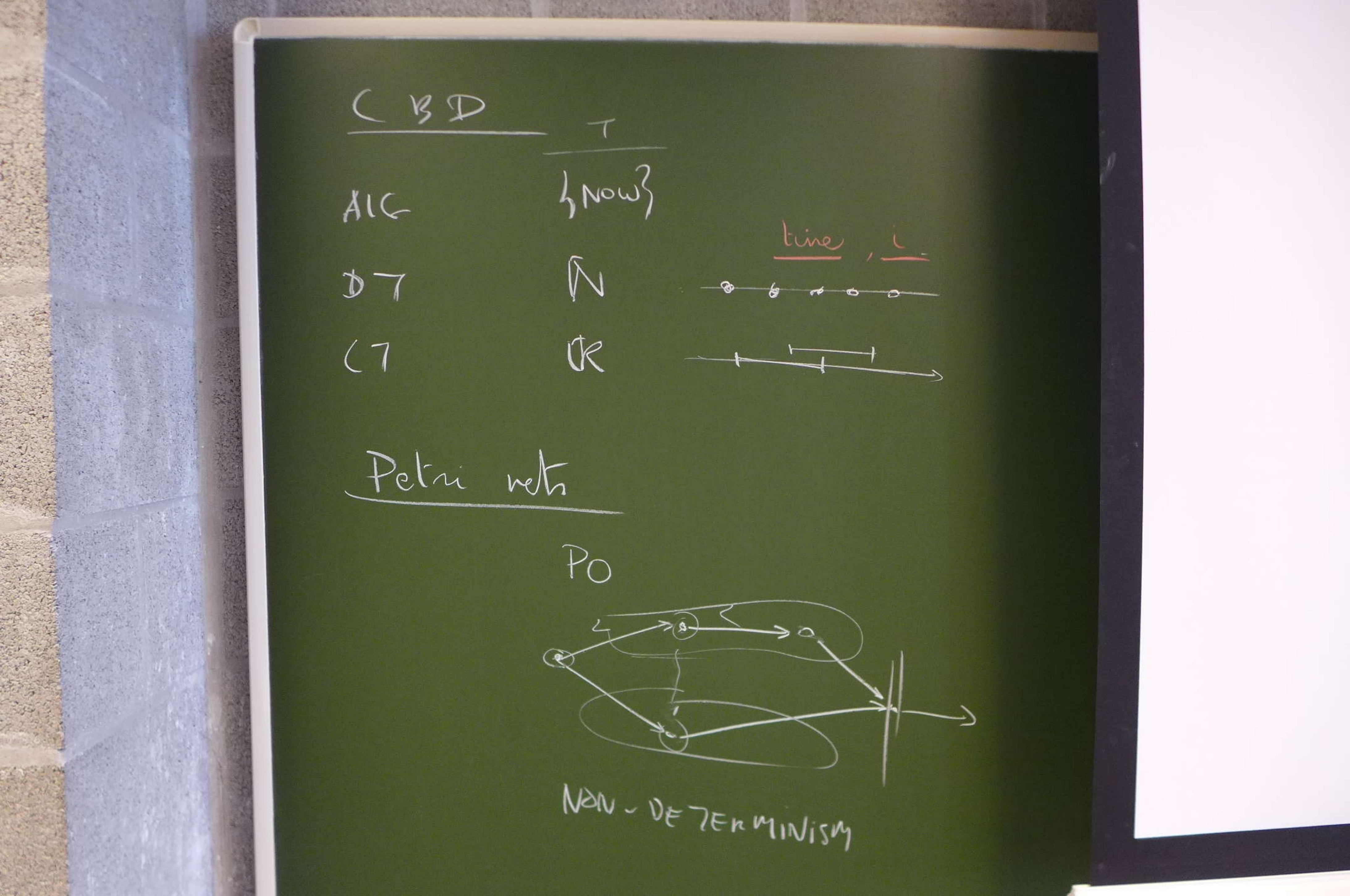
FRANÇOIS CELLIER

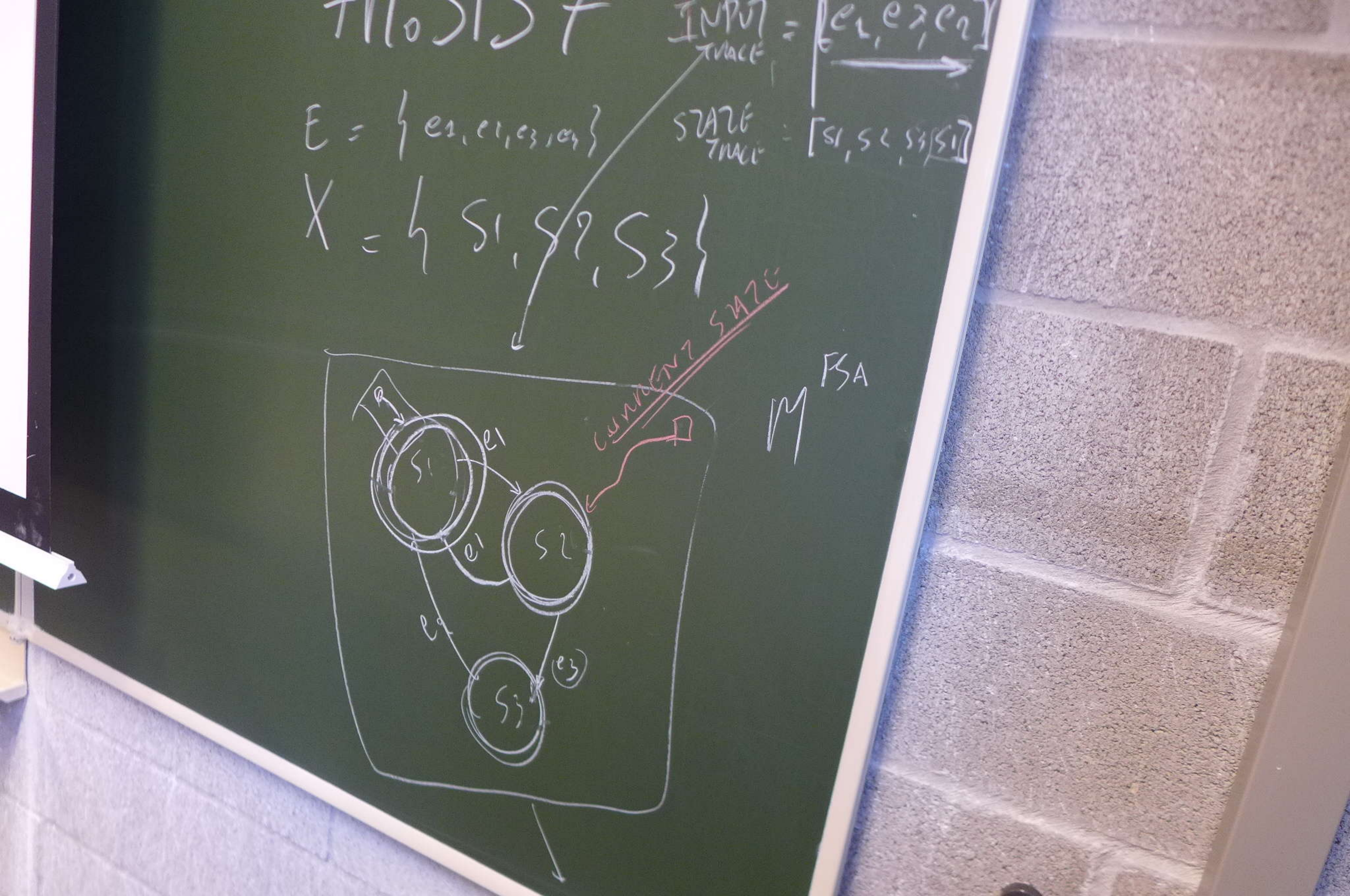
SYNCHRONOUS DATA



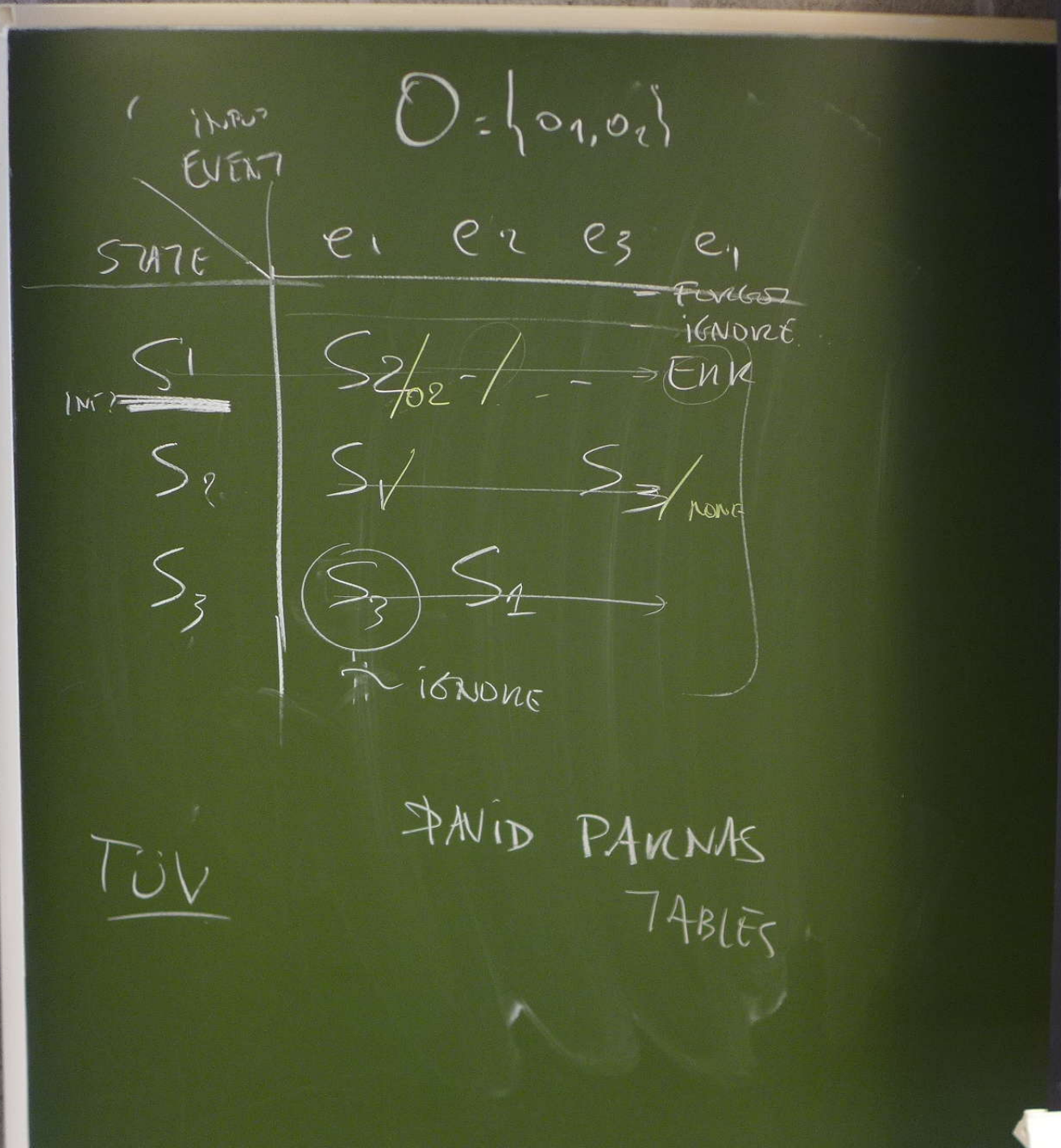
$$F = \frac{d(m \cdot v)}{dt} = \frac{dm}{dt} v +$$


k_r, k_i, k_D
V_n
V_i
$\frac{dv}{dt}$
$\left(\frac{dv}{dt}\right)_{MAX}$

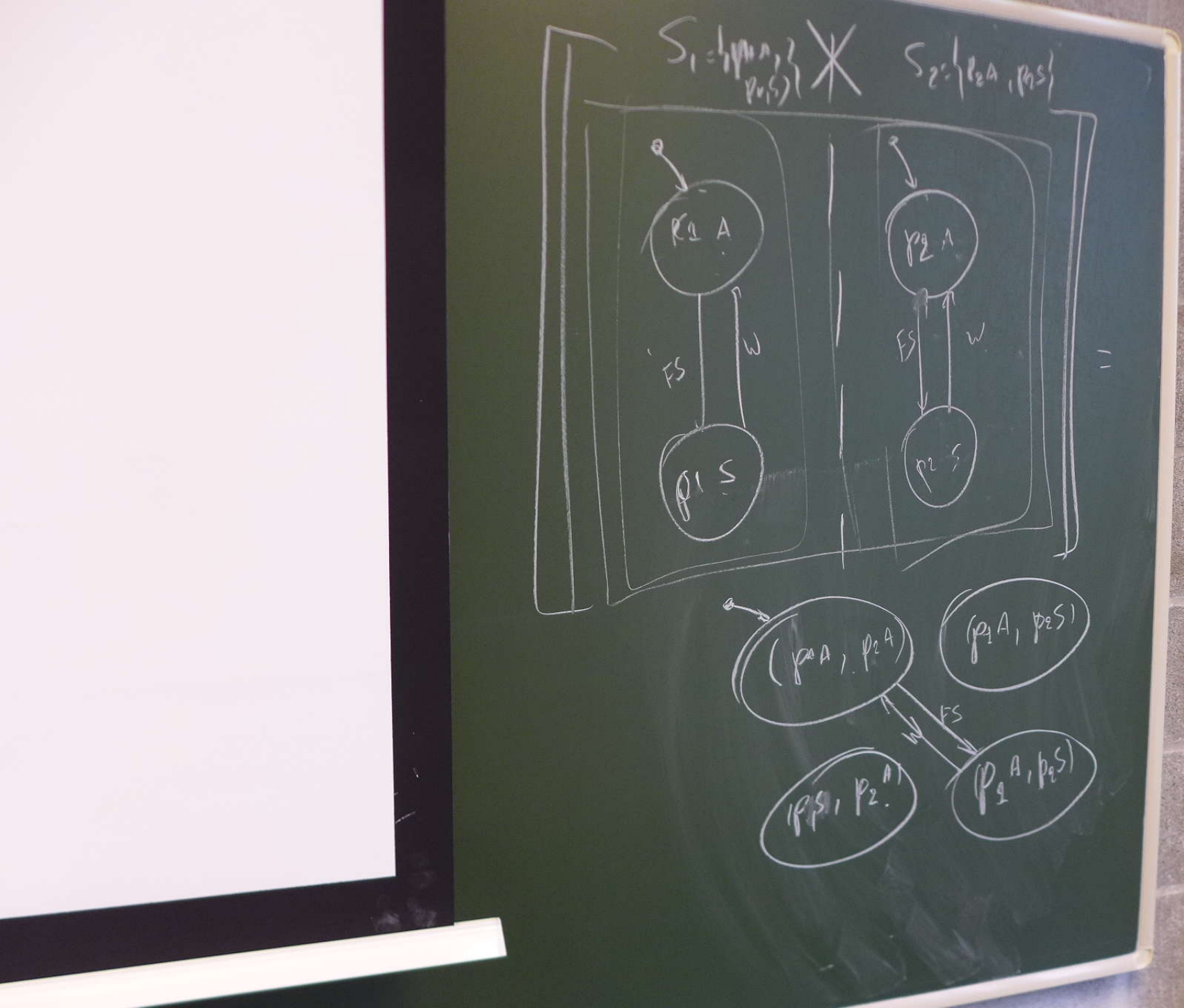

CBD
T
AIG
{NOW}
DT
ℕ
CT
ℝ
time
Petri nets
PO
NON-DETERMINISM

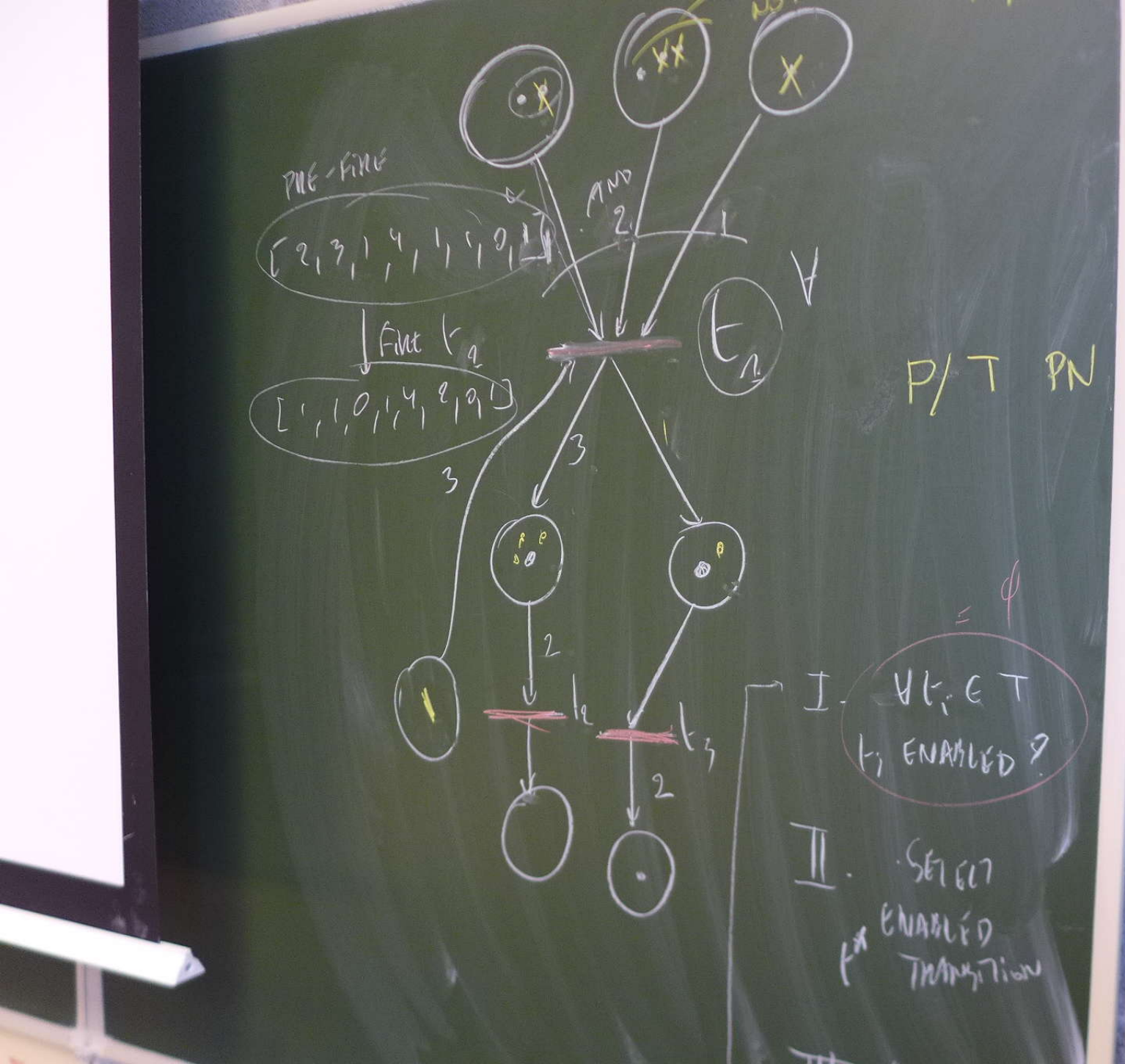


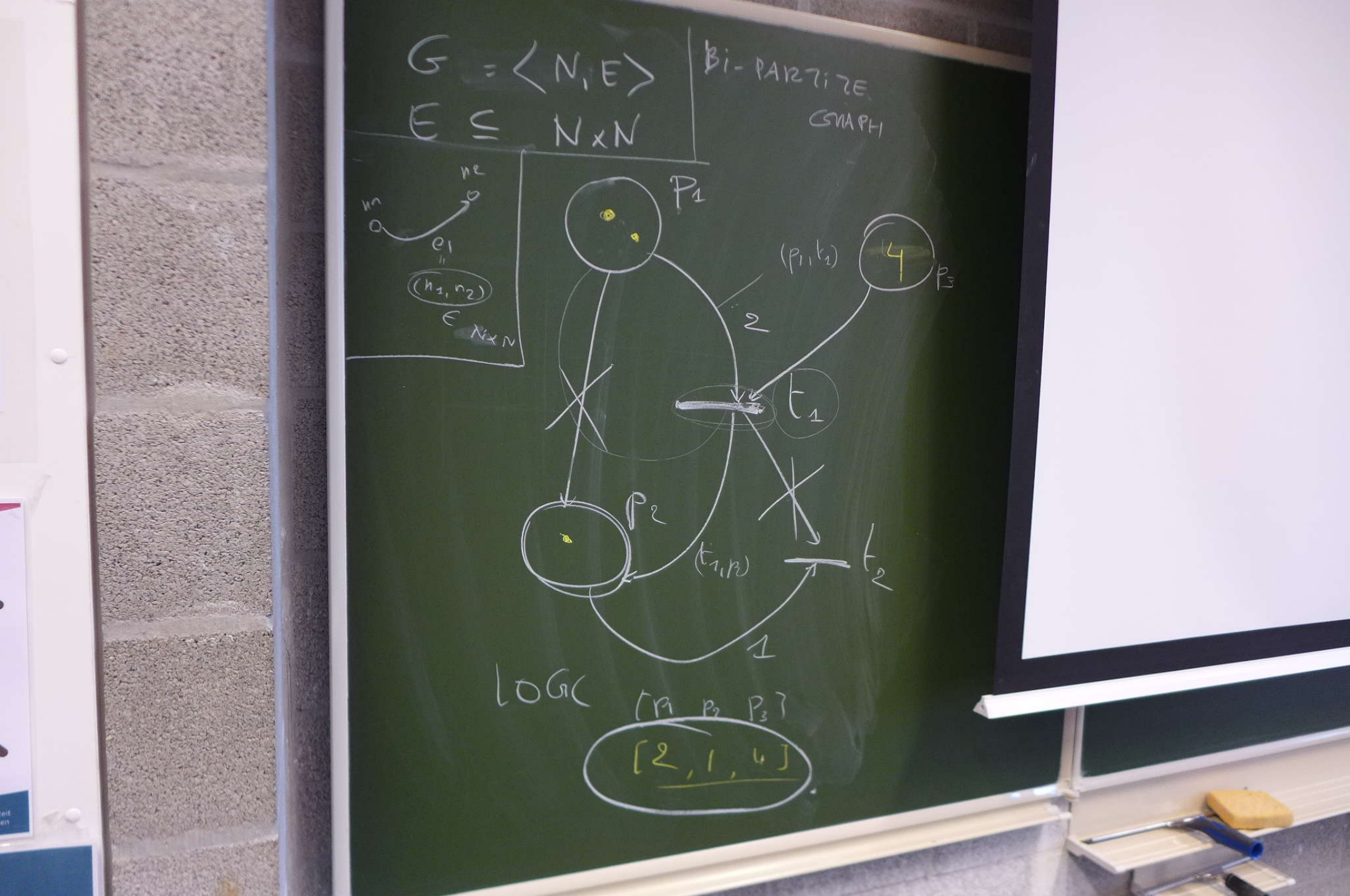
INPUT TRACE
STATE TRACE
X = {S1, S2, S3}
CURRENT STATE
M FSA
S1
S2
S3
e1
e1
e2
e3

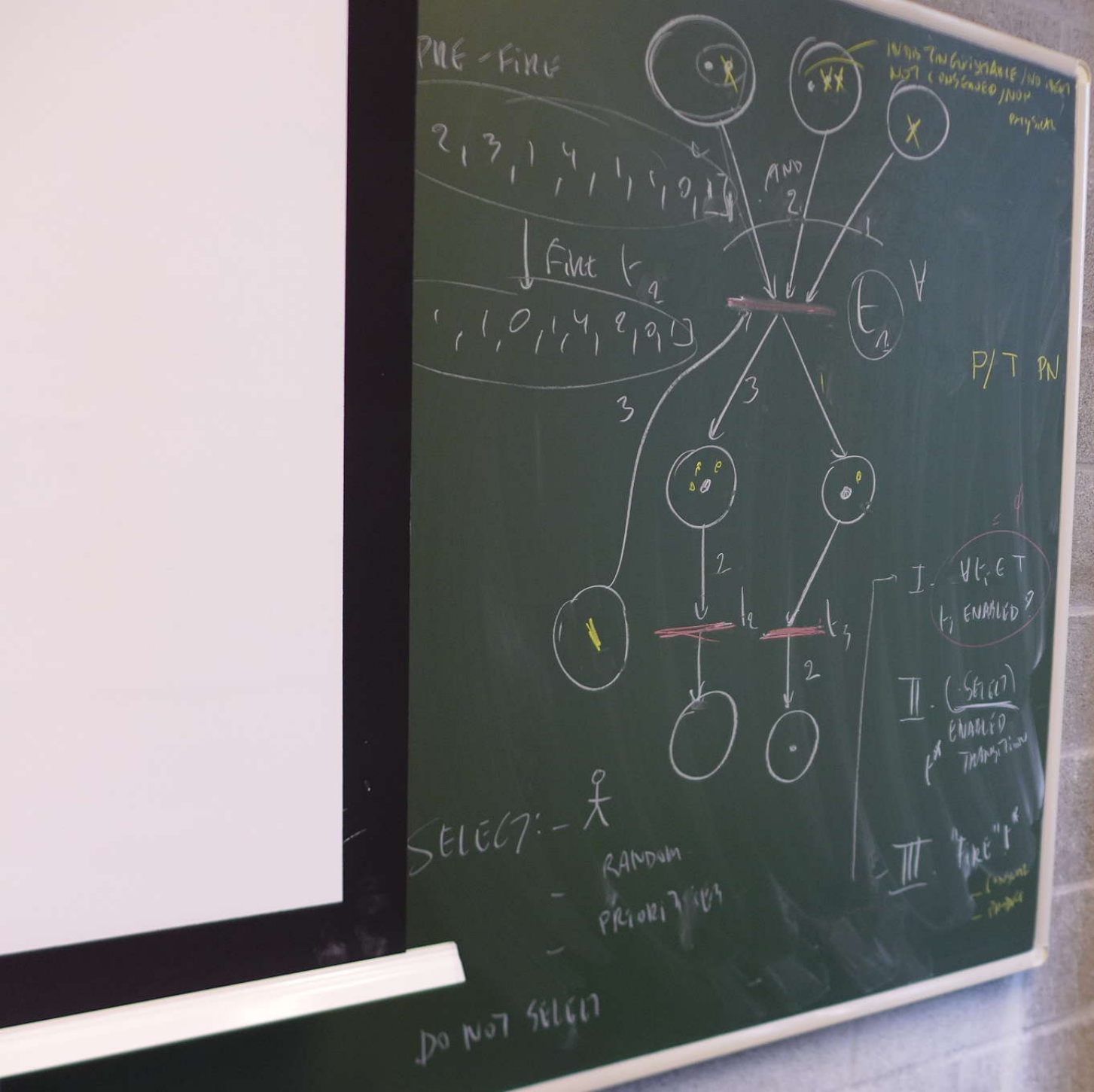

INPUT EVENT
STATE
e1 e2 e3 e4
FORGOT
IGNORE
S1
S2/O2
ERR
INIT
S2
S1
S3
MORE
S3
S4
IGNORE
TÜV
DAVID PARNAS
TABLES

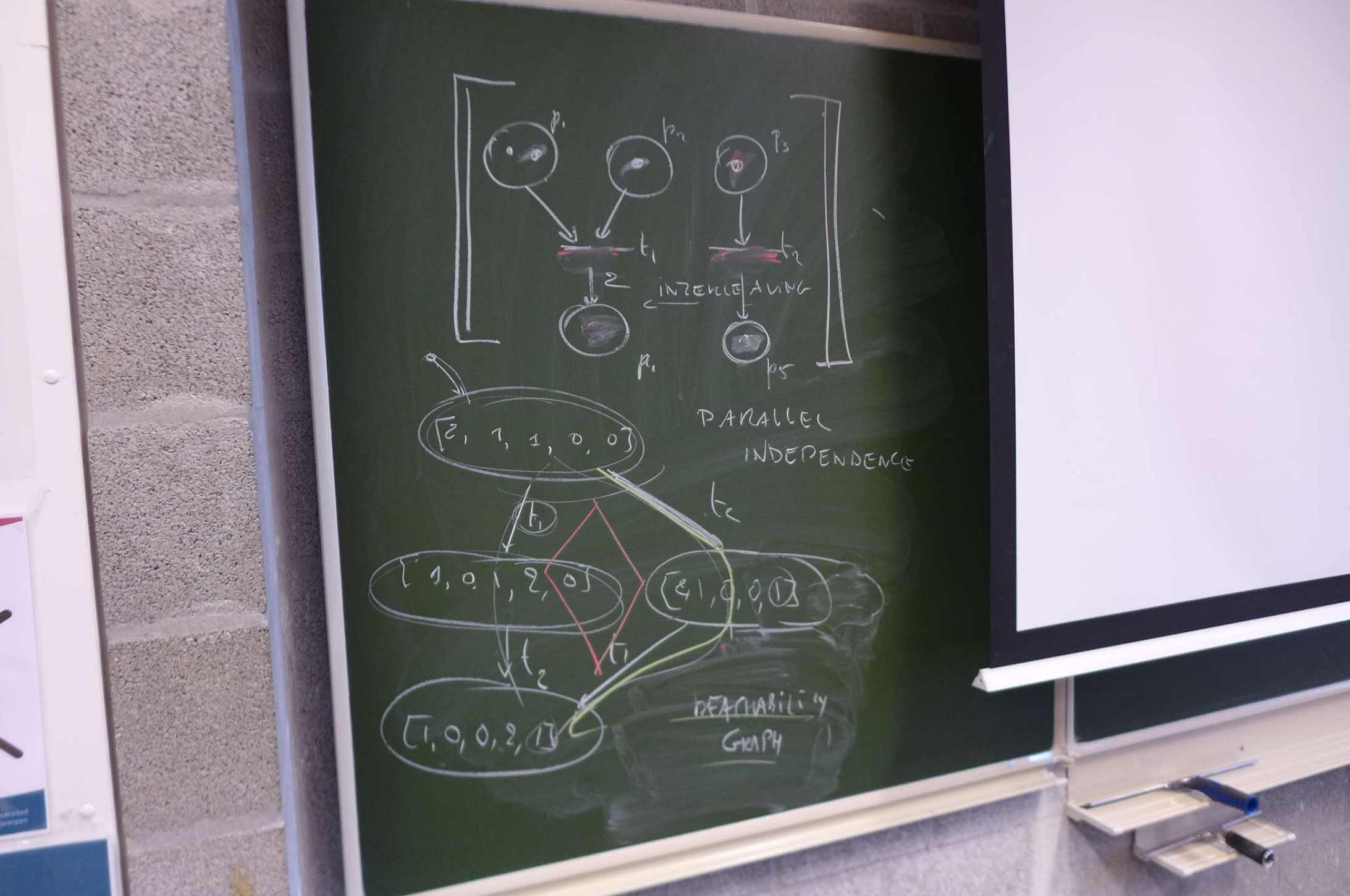
e_4
e_3
S
S_3
S_2
S_1
e_3
e_1
t
DD


FS
W
FS
W
=
FS


PRE-FIRE
AND
FIRE t_2
P/T PN
I. $\forall t_i \in T$
t_i ENABLED ?
II. SELECT
ENABLED
TRANSITION


G = ⟨N, E⟩
E ⊆ N × N
Bi-PARTITE GRAPH
n_1
n_2
e_1
(n_1, n_2)
$\in N \times N$
P_1
P_2
P_3
(P_1, t_1)
4
2
t_1
(t_1, P_2)
t_2
1
LOG(P_1 P_2 P_3)
[2, 1, 4]

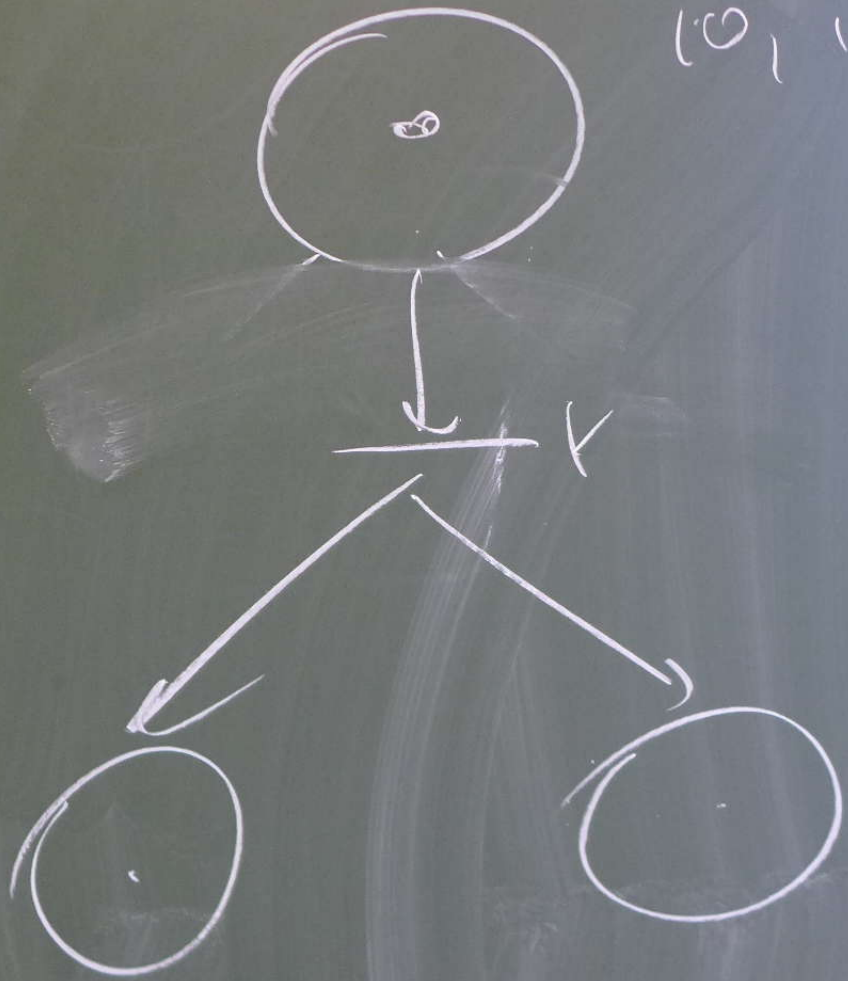

FIRE - FIRE
AND
P/T PN
SELECT:-
RANDOM
DO NOT SELECT

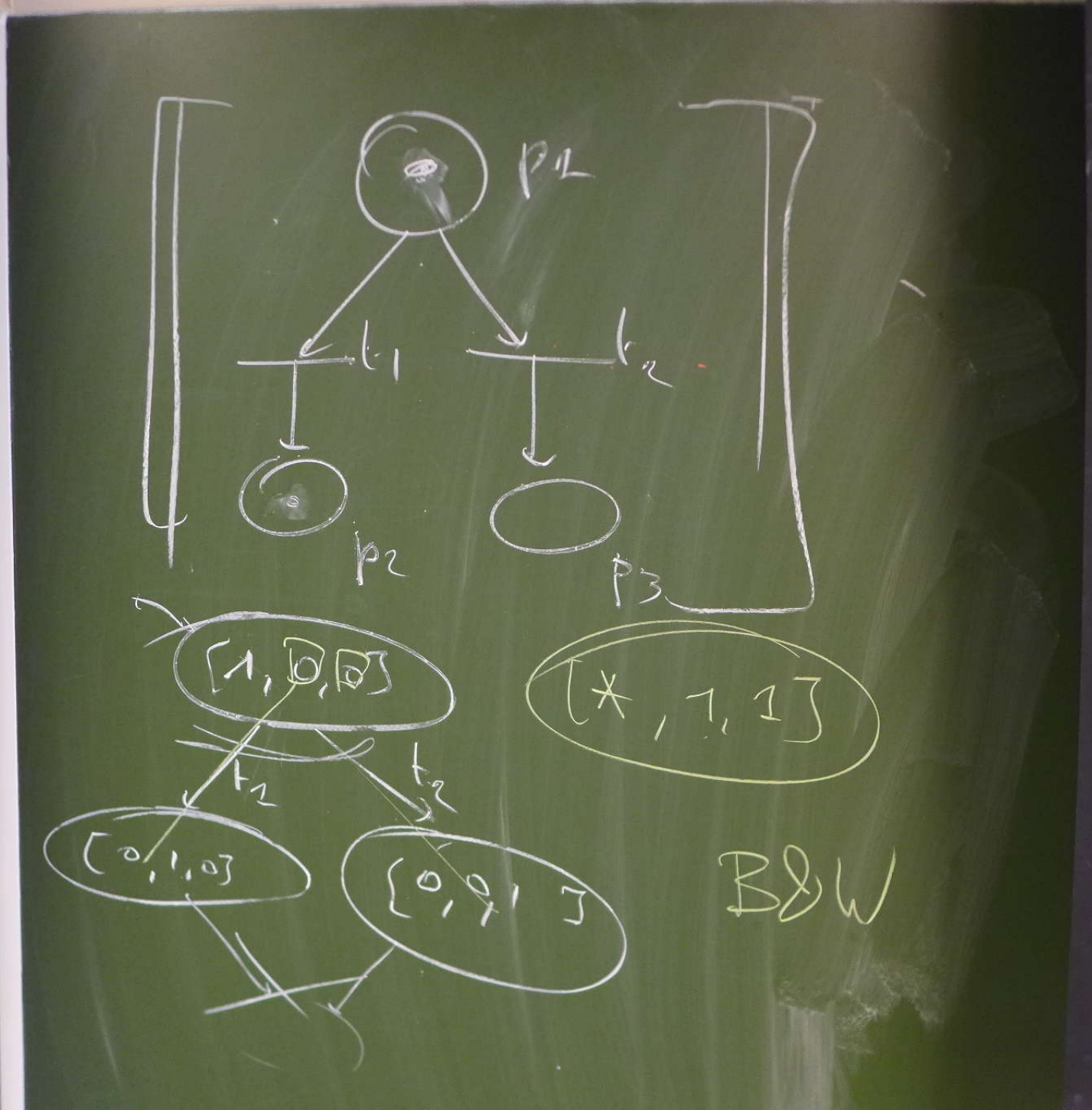

p1
p2
p3
t1
t2
2
INTERLEAVING
p4
p5
PARALLEL
INDEPENDENCE
[2, 1, 1, 0, 0]
t1
t2
[1, 0, 1, 2, 0]
[1, 0, 0, 1, 1]
t2
t1
[1, 0, 0, 2, 1]
REACHABILITY
GRAPH

[1, 0, 0]

↓

[0, 1, 1]




P1
t1
t2
P2
P3
[1,0,0]
[*,1,1]
t1
t2
[0,1,0]
[0,0,1]
B&W

INITIAL

$\pi(p)$

$\pi(p \cdot succ) =$
$k - \pi(p)$

CHOICE

GENERATOR

SPLIT

CHECK

READ ONLY

JOIN
SYNCH

PROCESS

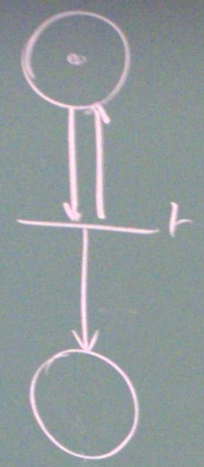
PARALLEL INDEPENDENCE

INTERLEAVING IS ARBITRARY

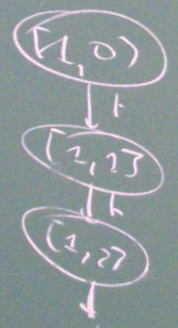
ABSTRACT

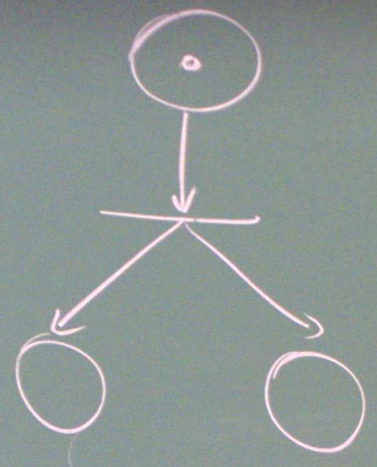
Flow of Control

CHOICE

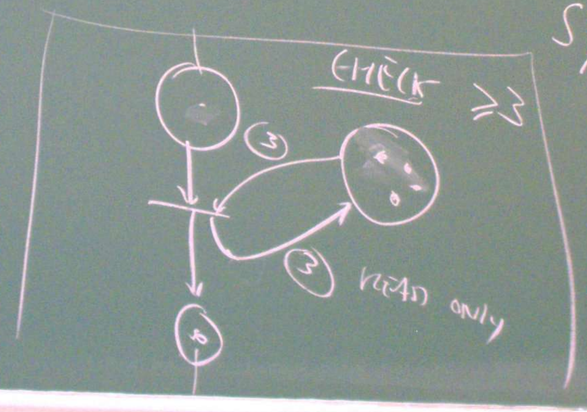


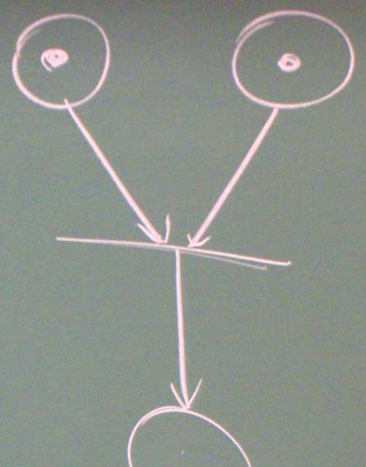
GENERATOR



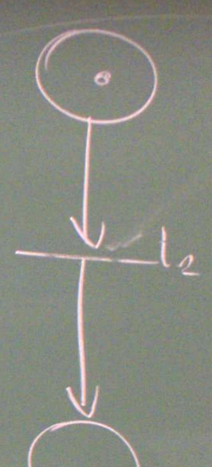


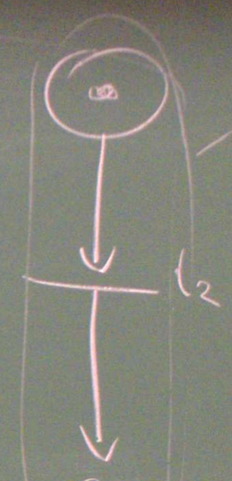
SPLIT





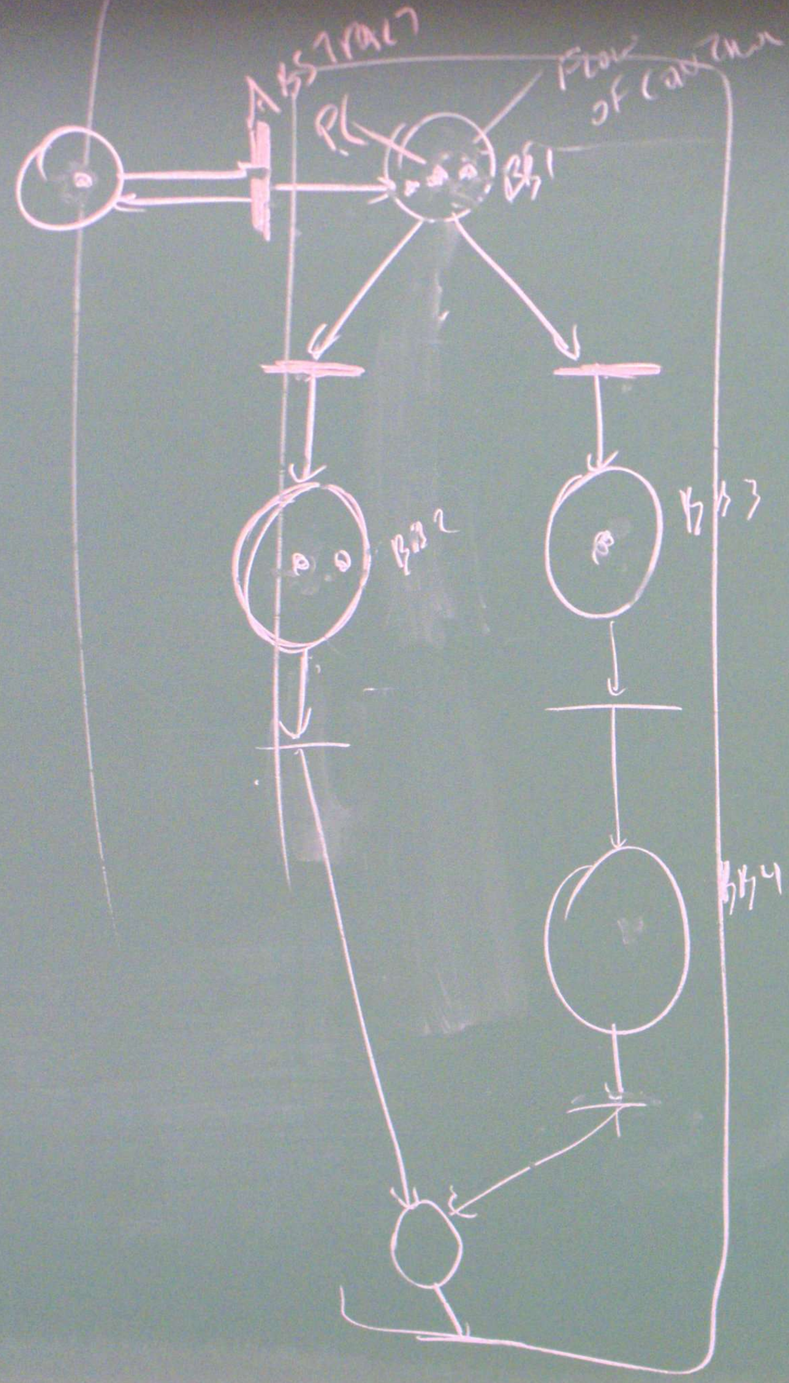
JOIN
SYNCH

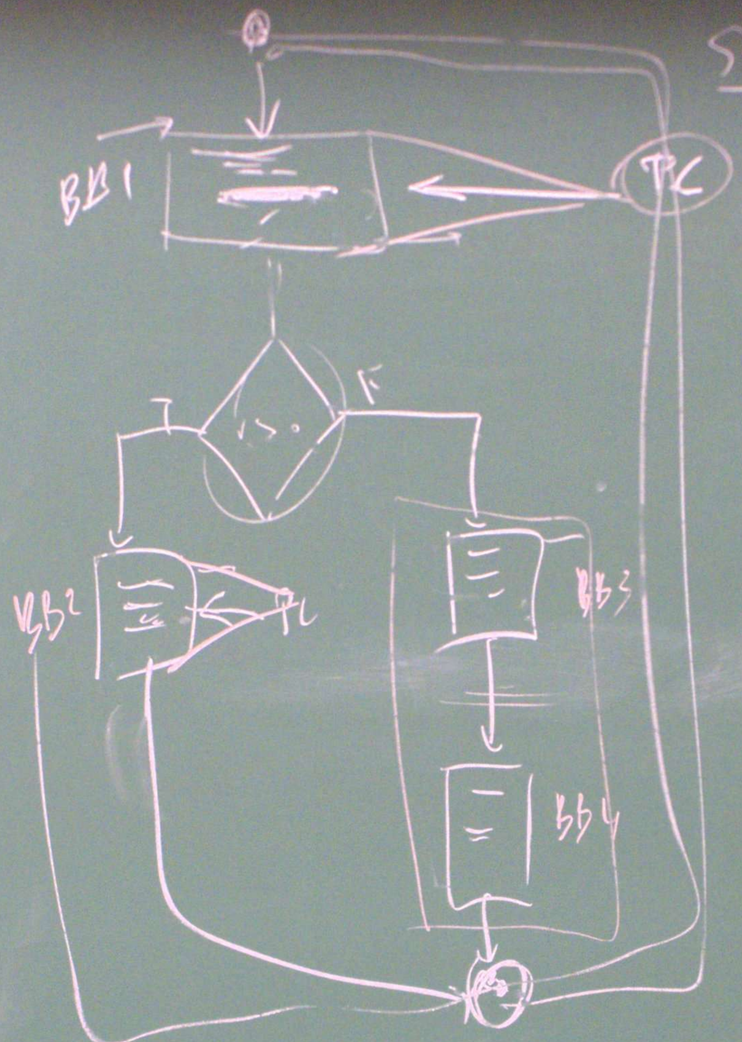




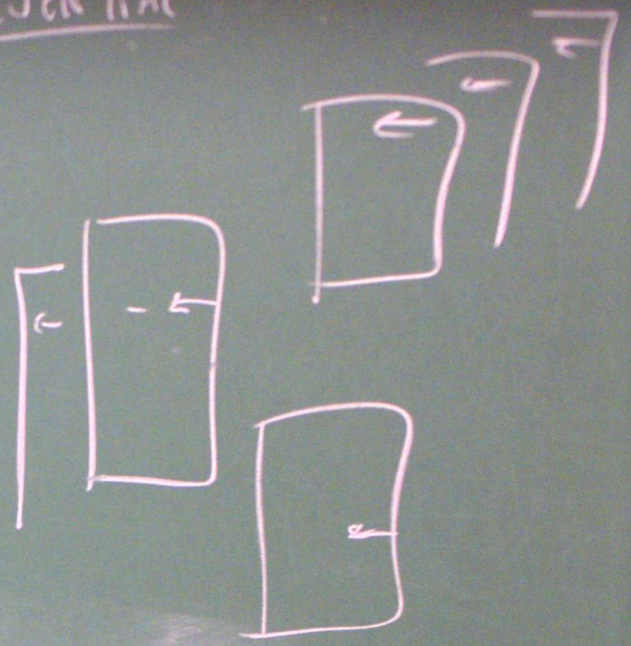
PARALLEL INDEPENDENCE

INTERLEAVING IS ARBITRARY

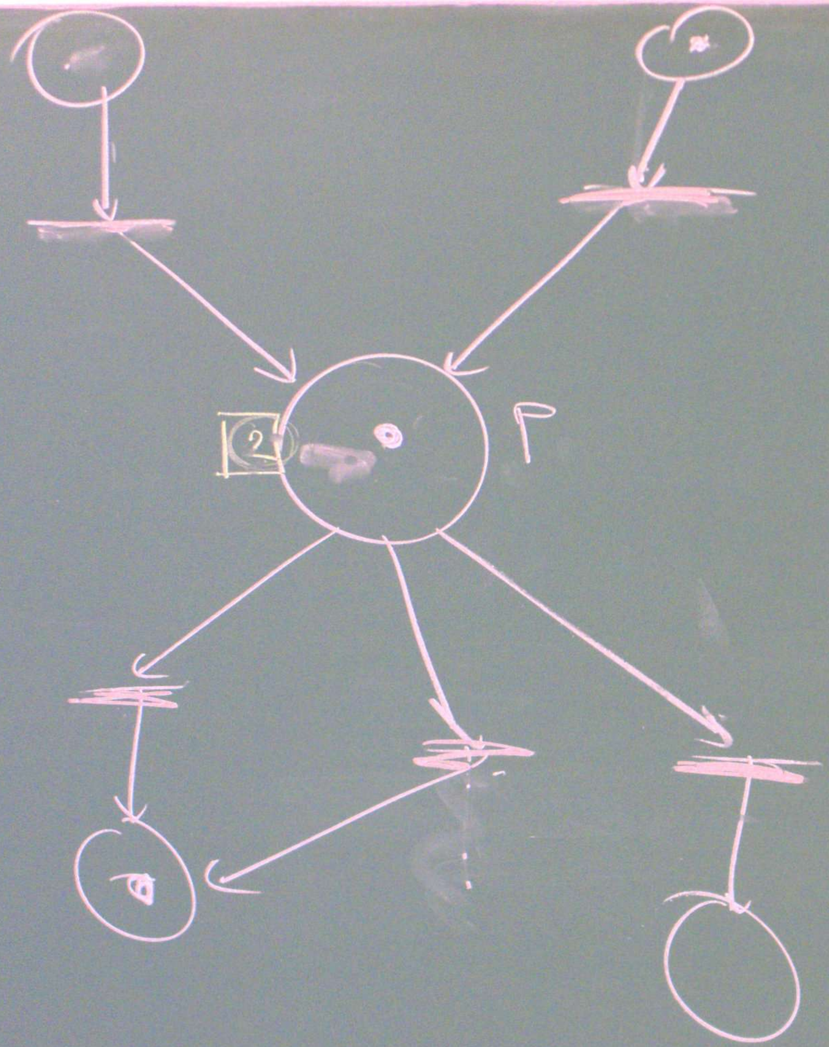




SEQUENTIAL



PARALEL



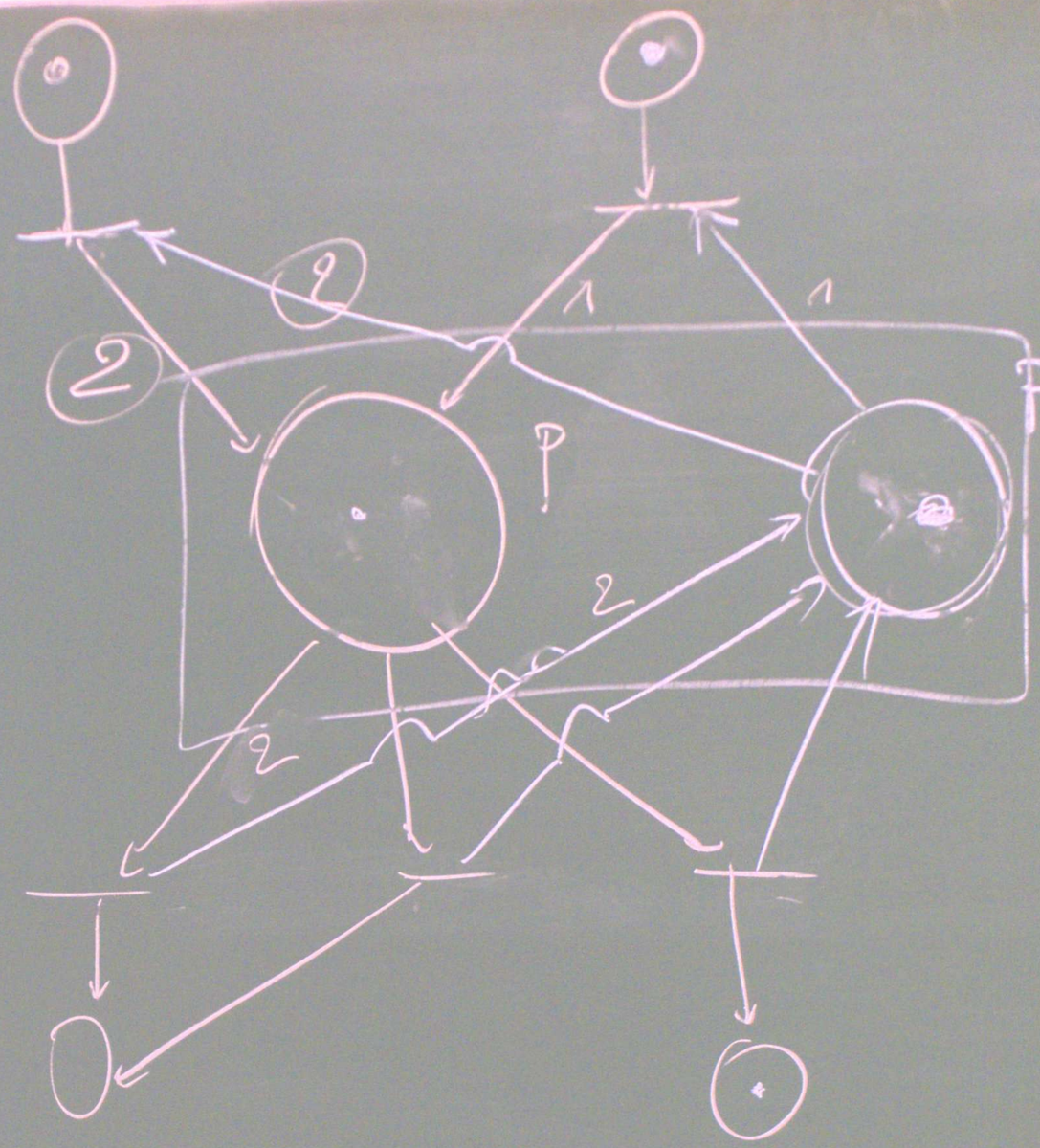
CAPACITY-CONSTRAINED PN

"SYNTACTIC SUGAR"

≡

EXPRESSIVENESS

PN



"DUAL"

P_SLACK

INITIAL:

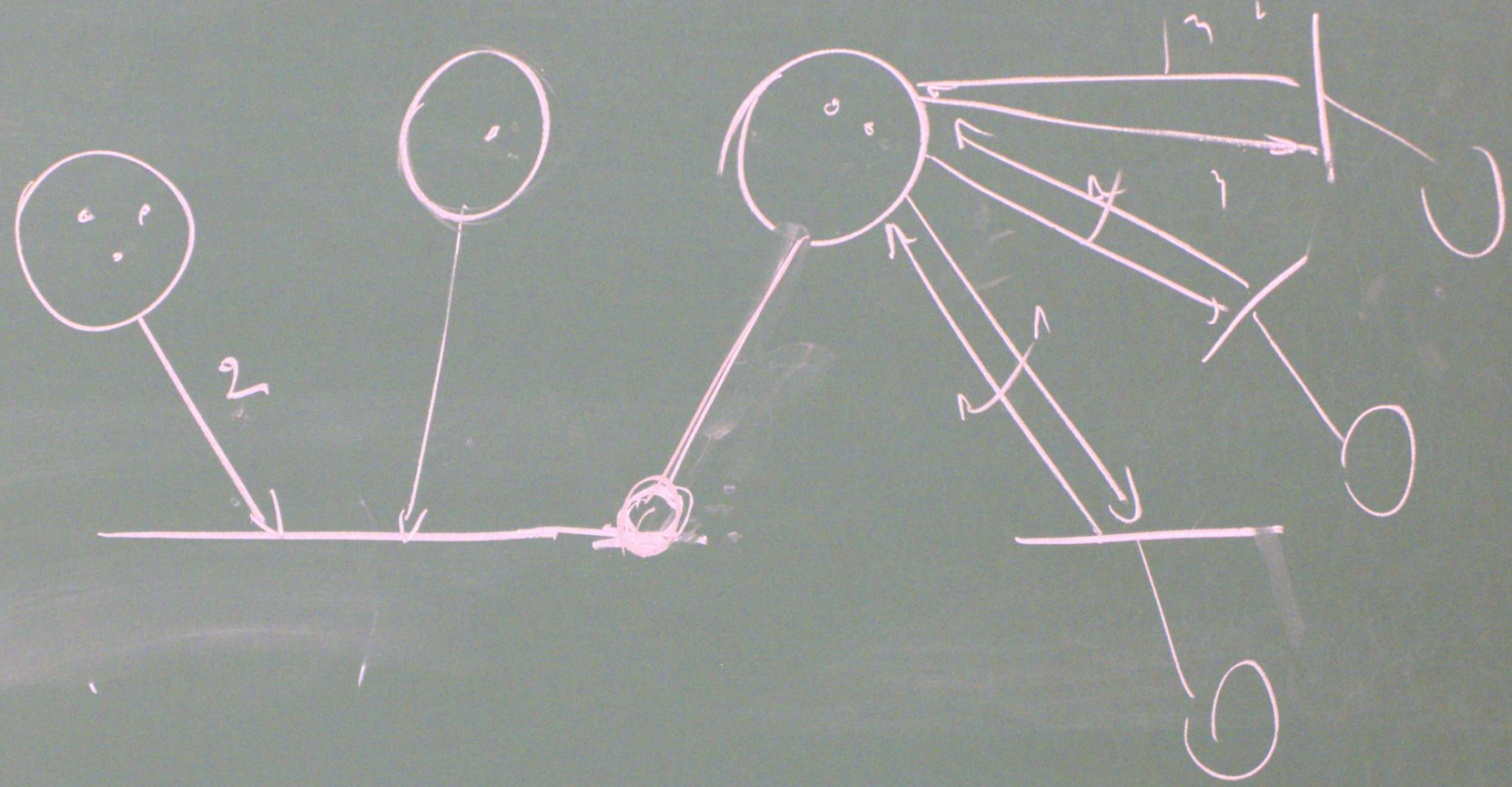
$x(p)$

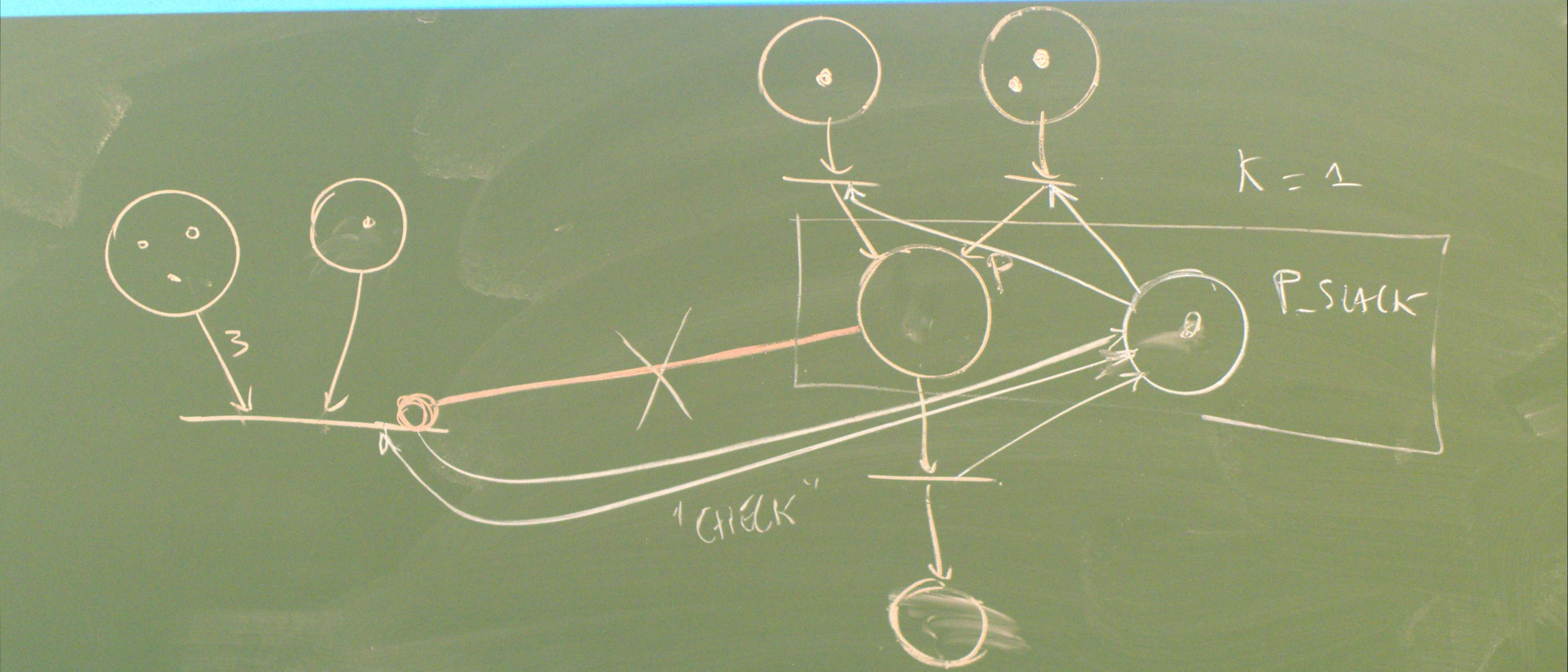
$x(p\_slack) =$

$k - x(p)$

EXPRESSIVENESS $\neq$

P/T P.N. WITH INHIBITOR ARCS $\sim$ TURING MACHINE

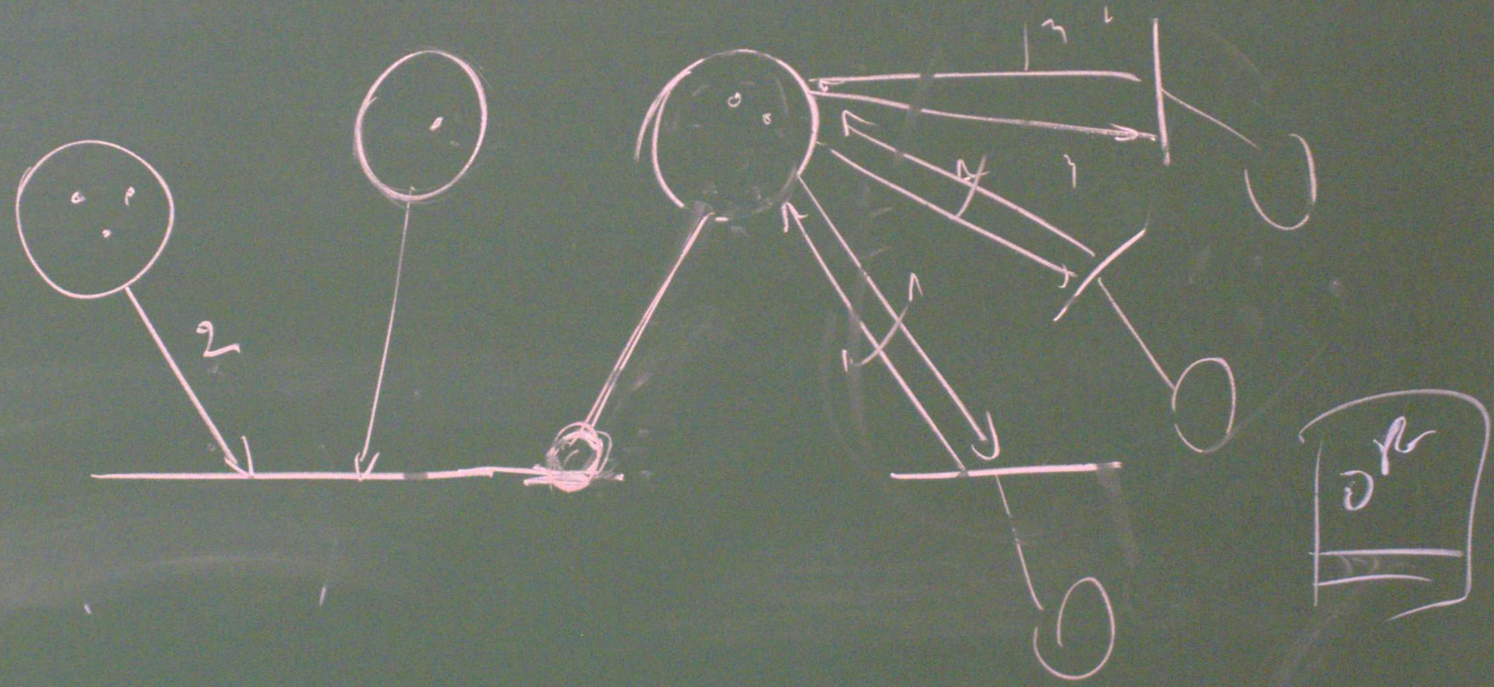



3
K = 1
P_STACK
"CHECK"

41/69

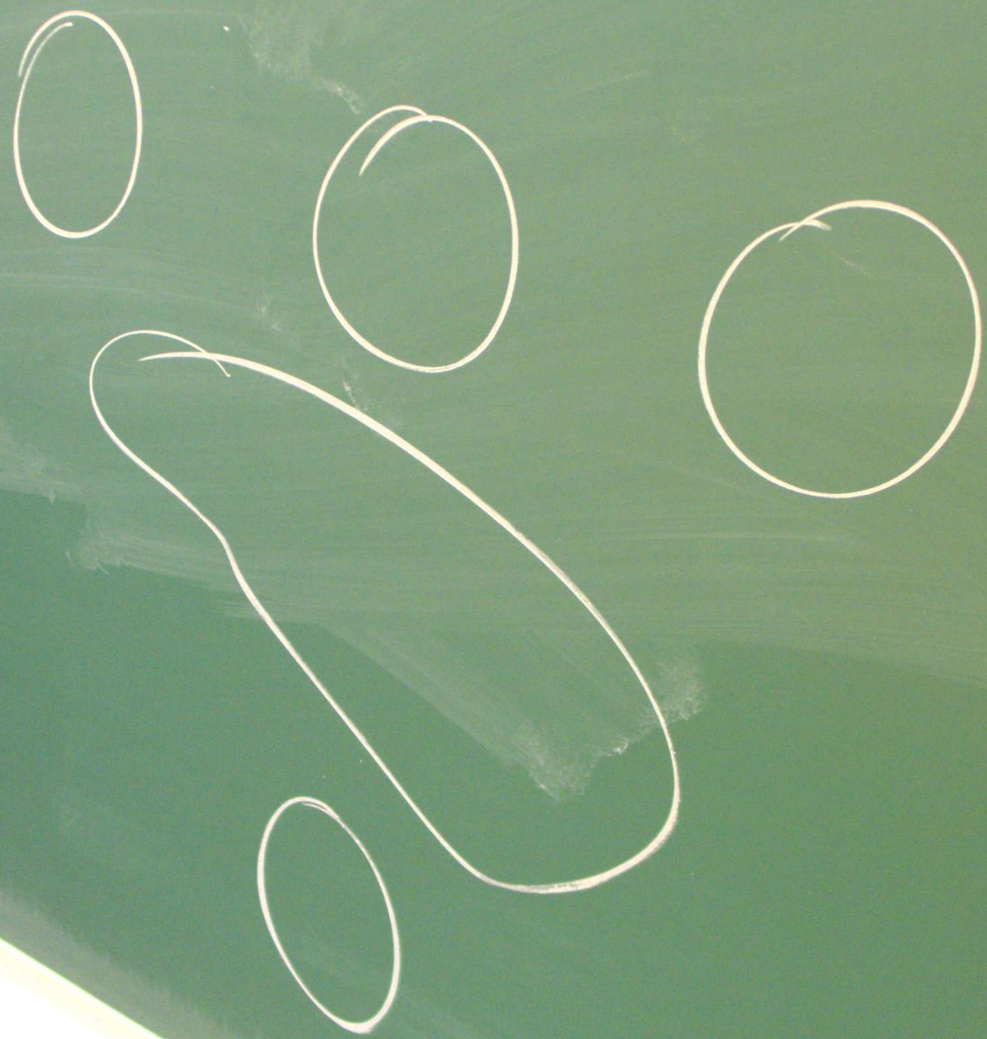
EXPRESSIVENESS $\neq$

P/T P.N. WITH INHIBITOR ARCS $\sim$ TURING MACHINE

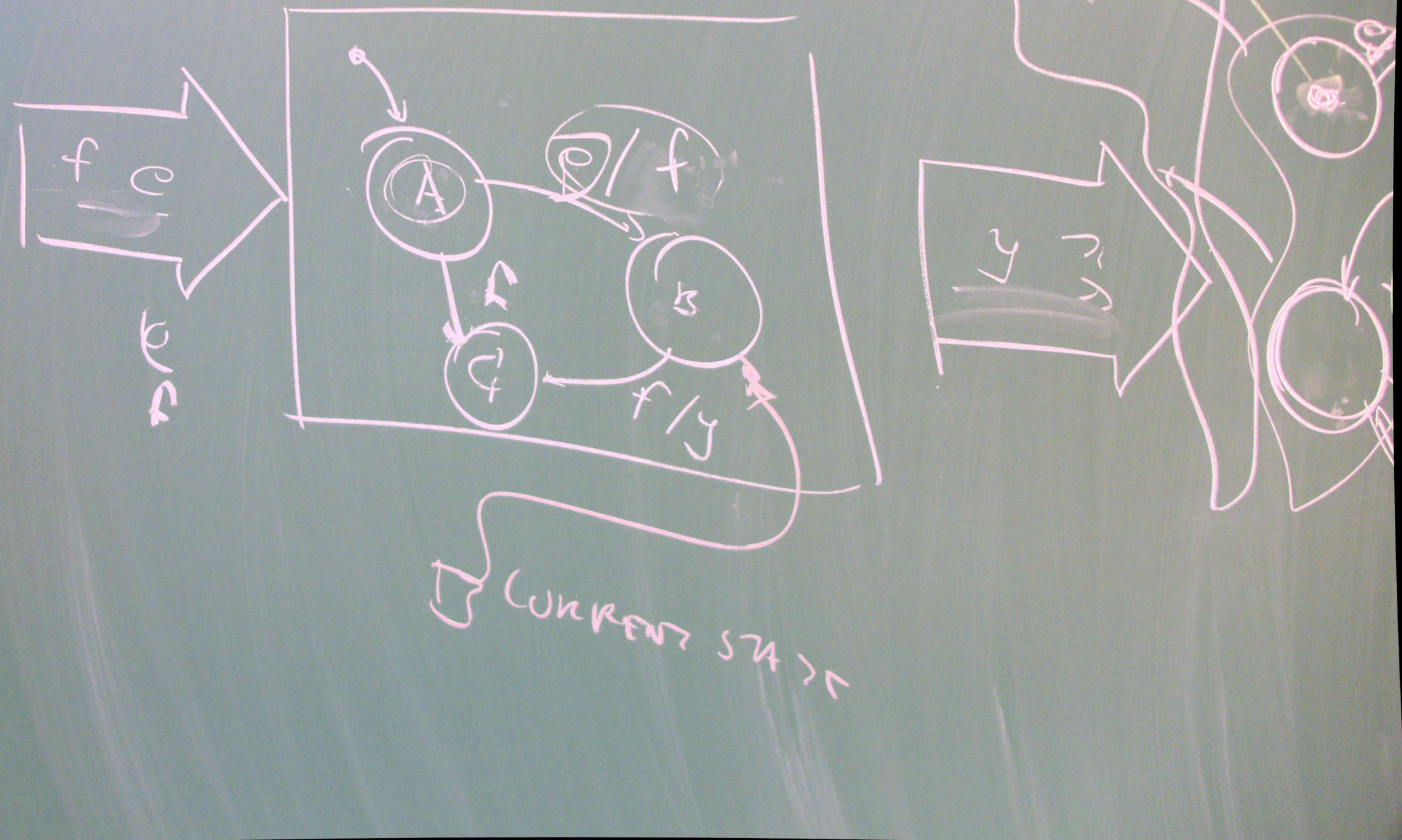


Hans Vangheluwe

OR



DFSA



PRESENCE OF

CHECK WHEN

P/7 PN

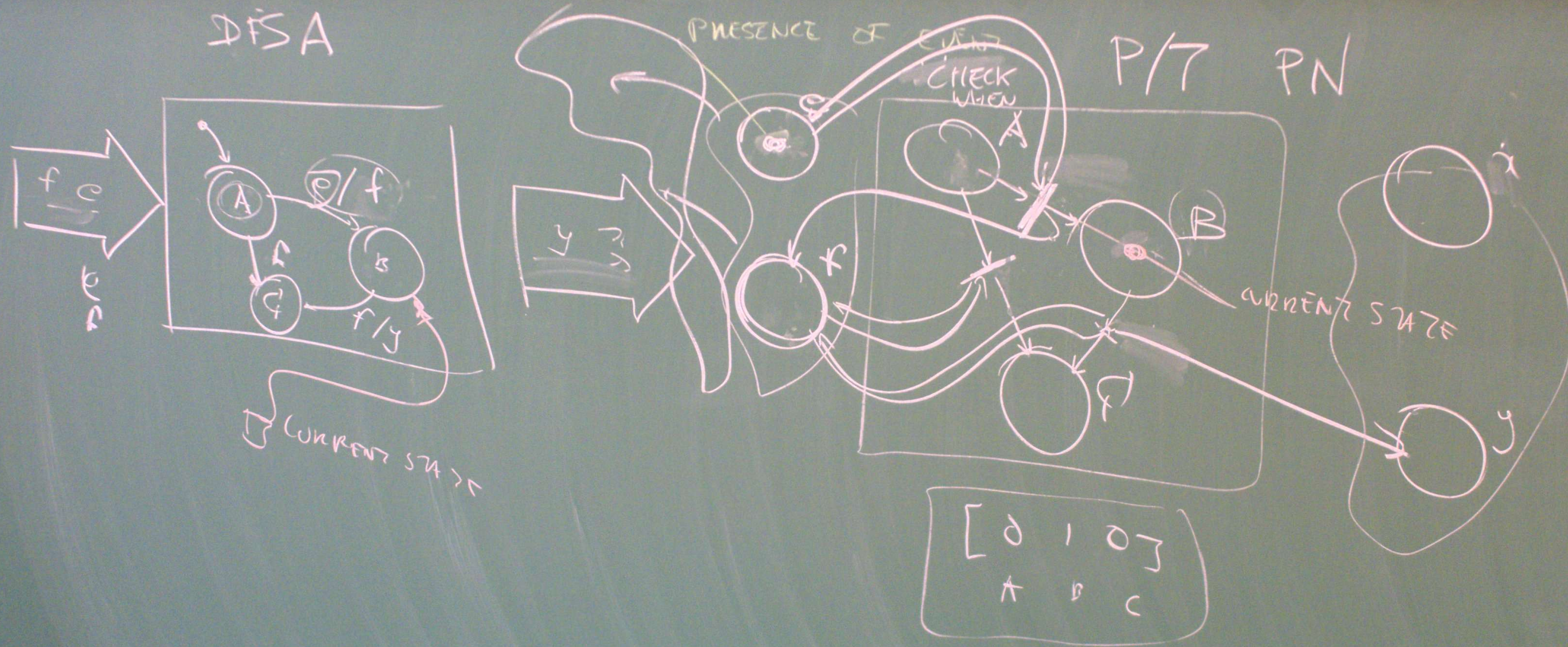
A

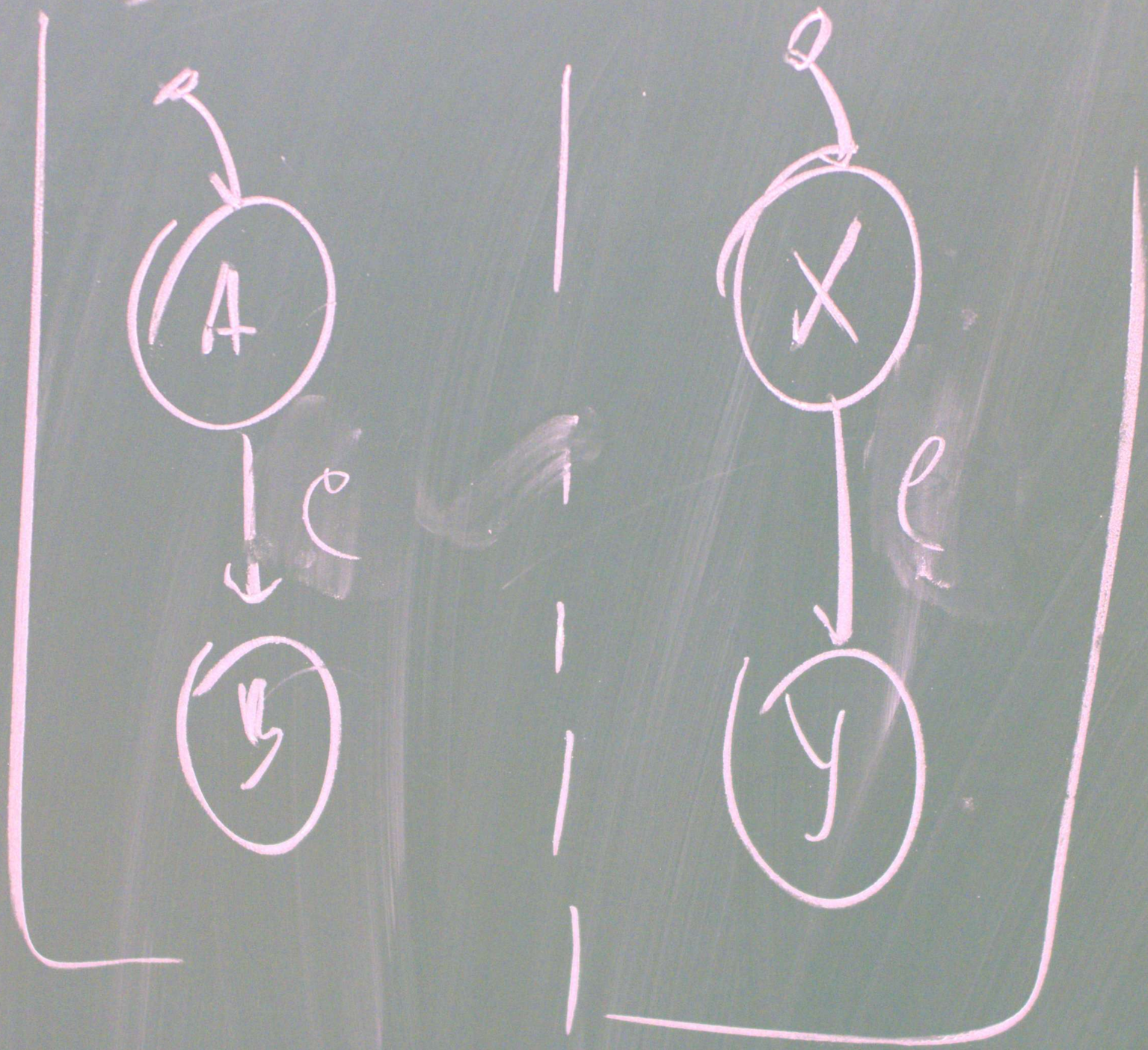
B

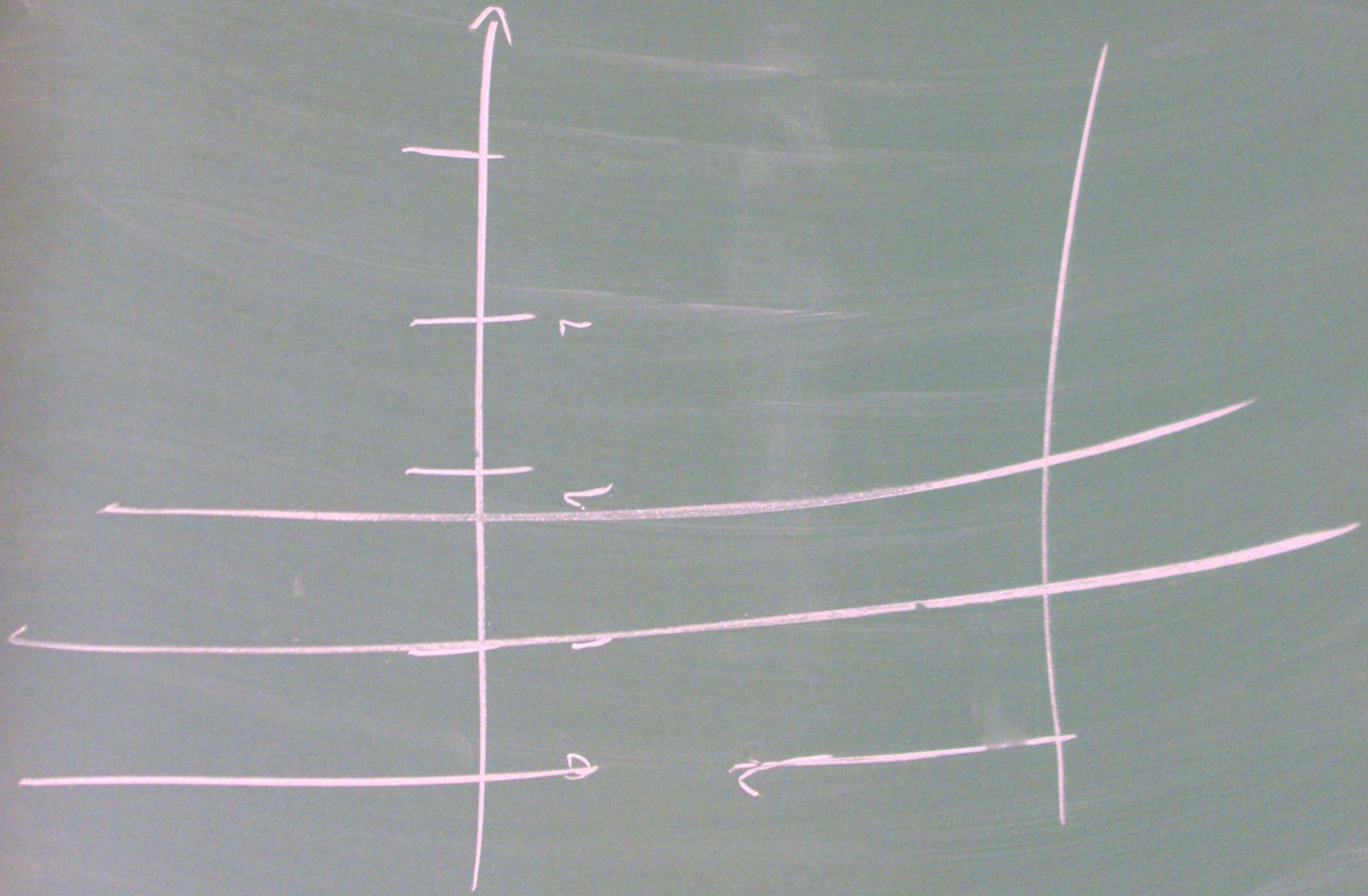
CURRENT STATE

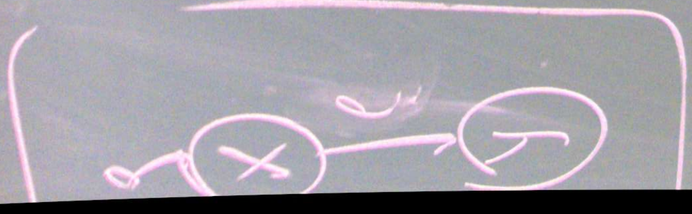
[0 1 0]

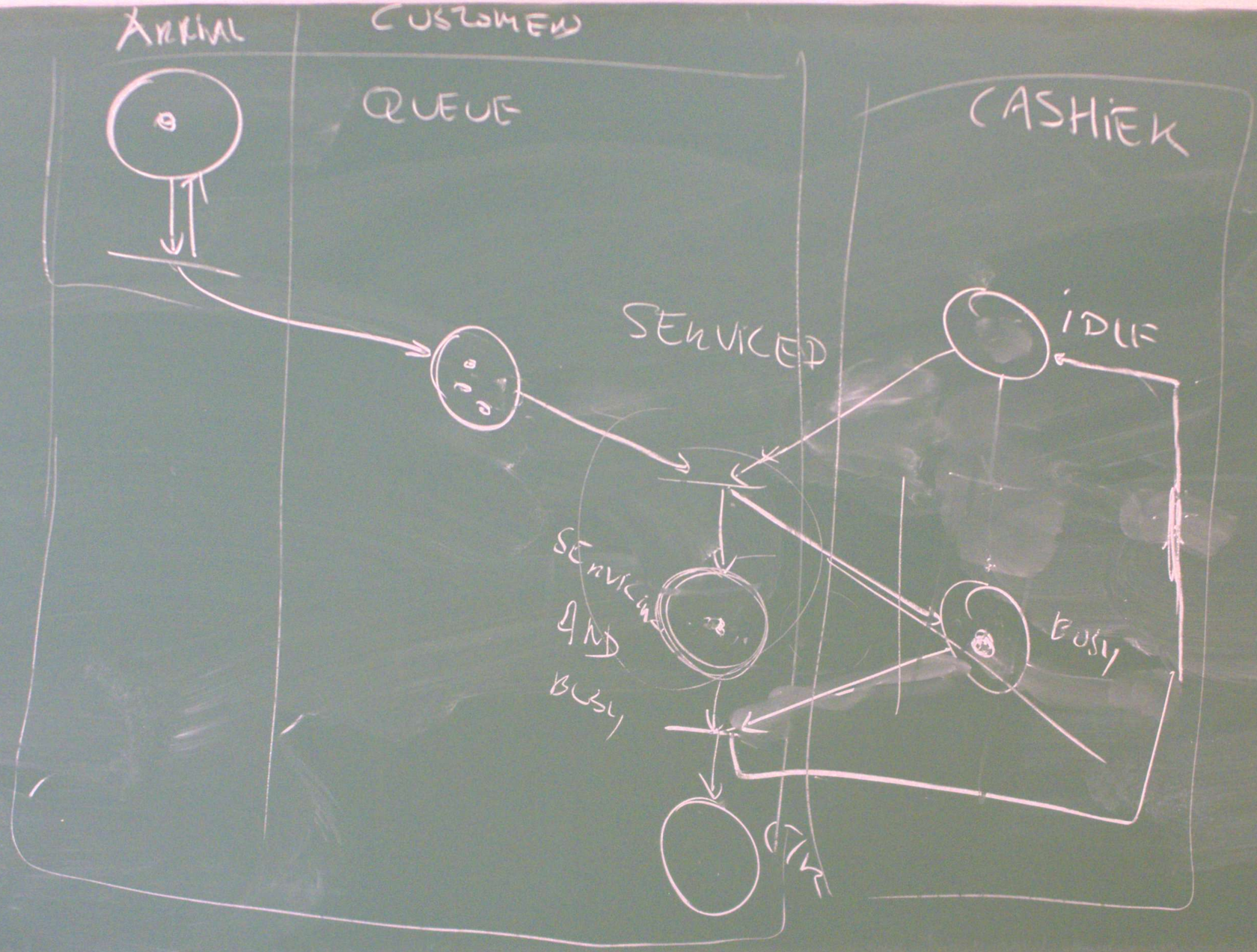
A B C


DFSA
PRESENCE OF
CHECK
P/T PN
CURRENT STATE
CURRENT STATE
[0 1 0]
A B C

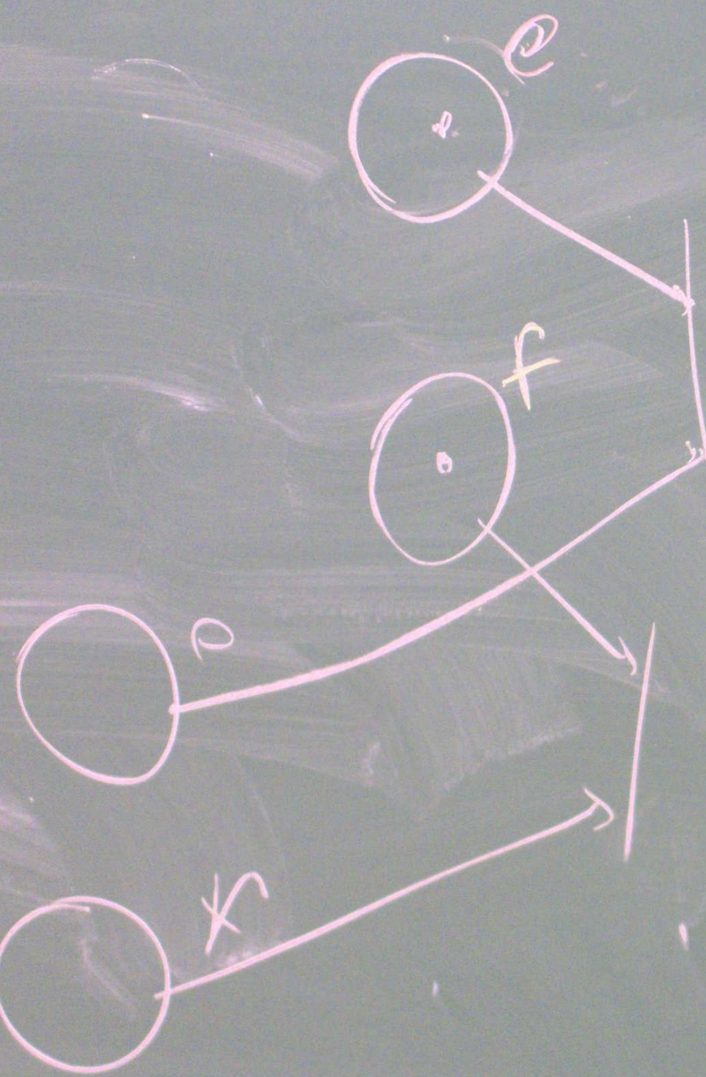

A
X
y
y


2
1
0

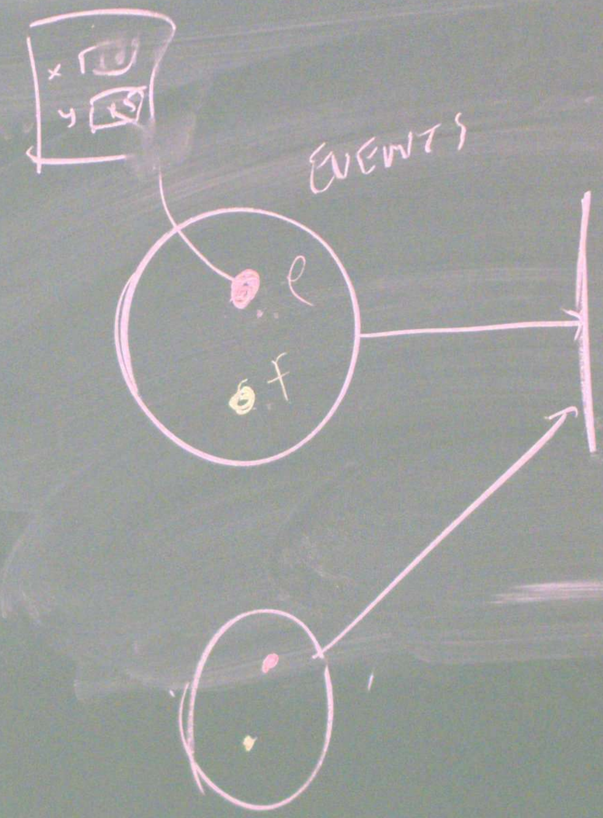

x
y


ARRIVAL
CUSTOMER
QUEUE
CASHIER
SERVICED
IDLE
SERVICING
AND
BUSY
BUSY
CLERK

P/T NET



COLOURED P/T

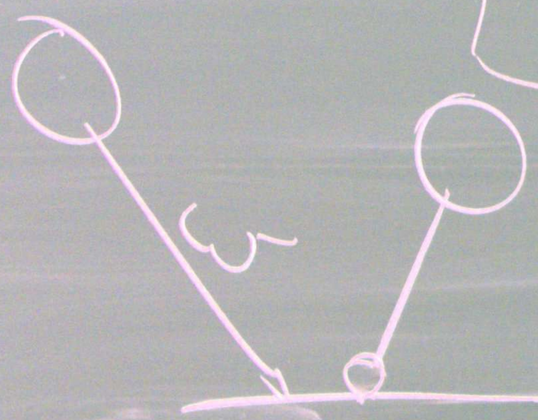


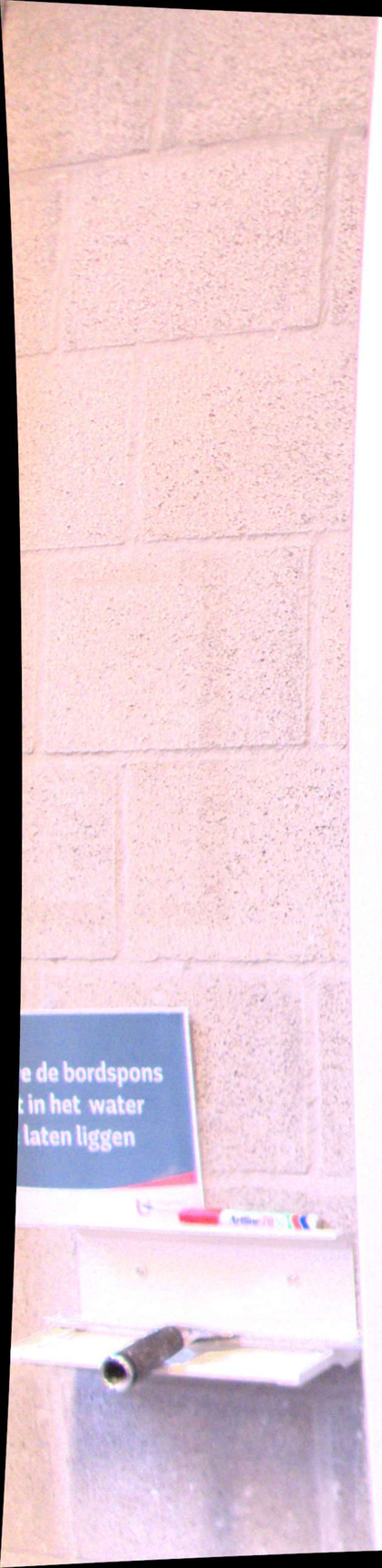
COLOURED PN
P
GP
RP
WAIT
[1, 0]
[0, 1]
COLOURS
PLACES
CPN tools

PLACE / TRANSITION PN

P/T PN

INHIBITOR ARCS




e de bordspons
in het water
laten liggen


N
K
K-N
K-N
K
N
DRIVEN


CUSTOMER
ITEMS
Φ3
Φ2
Φ1
XP
AGILE


3
2
1
items
customer
items

Φ_3 Φ_2 Φ_1

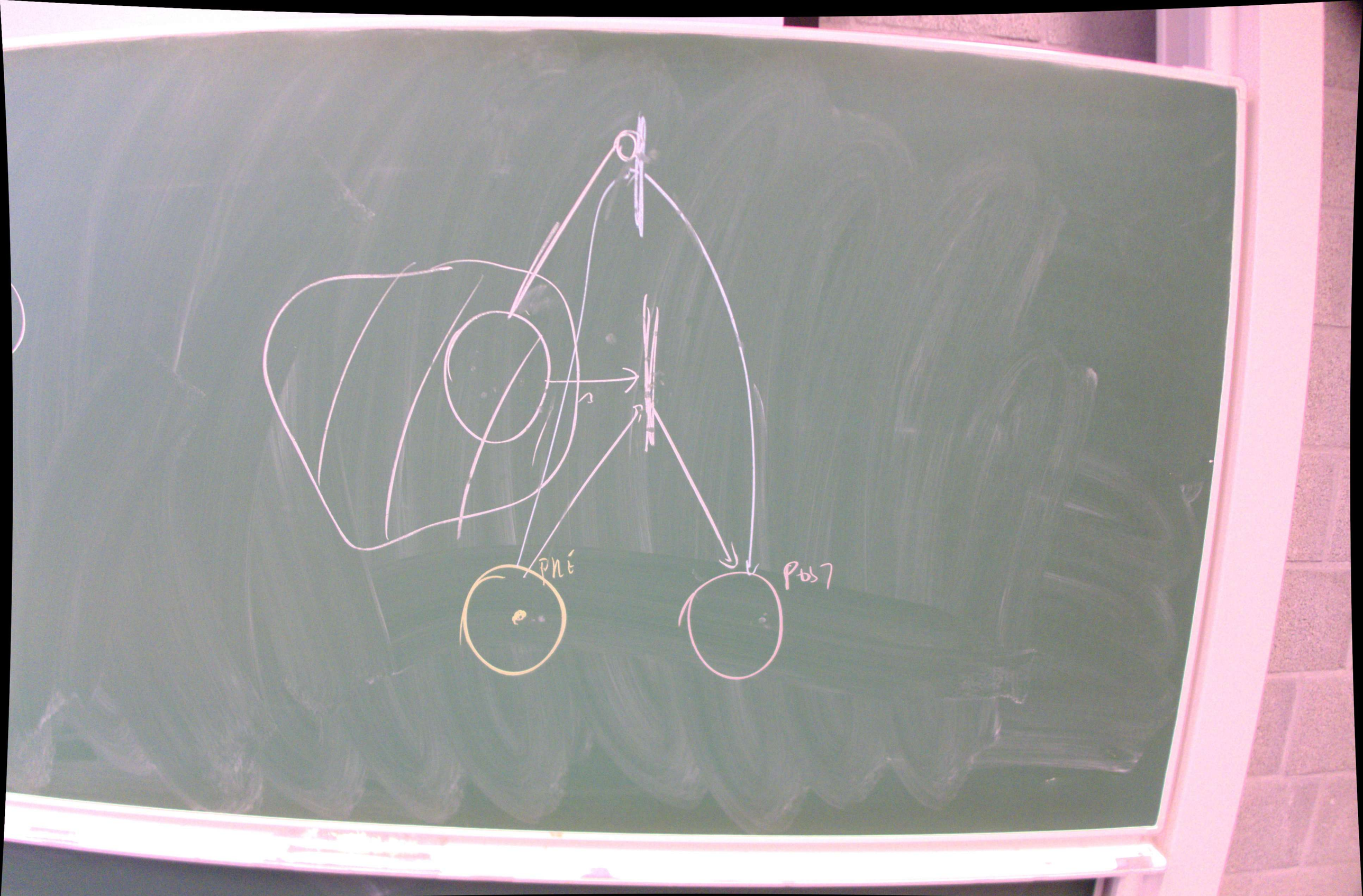
XP

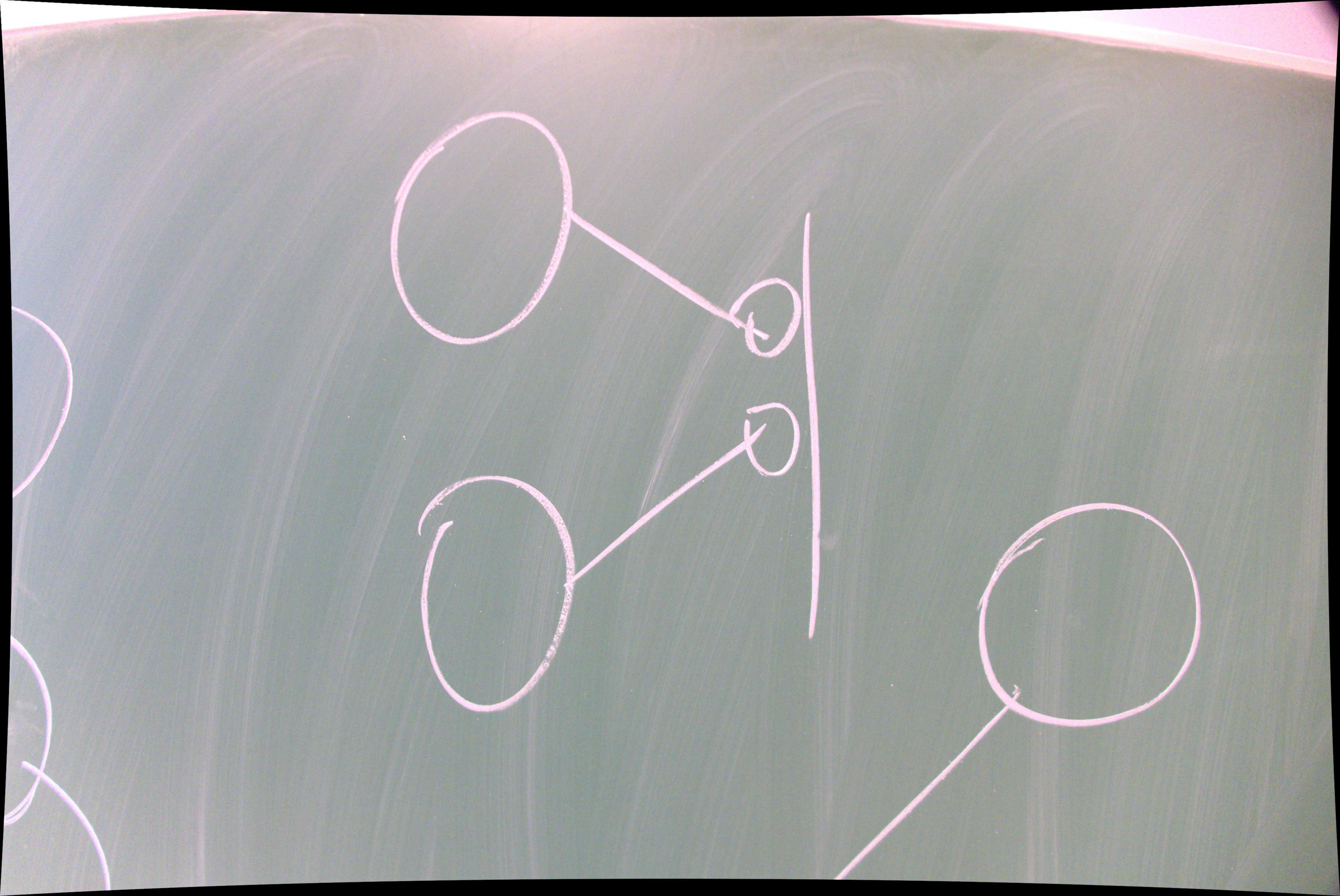
AGILE

TEST-DRIVEN

INCREMENTAL

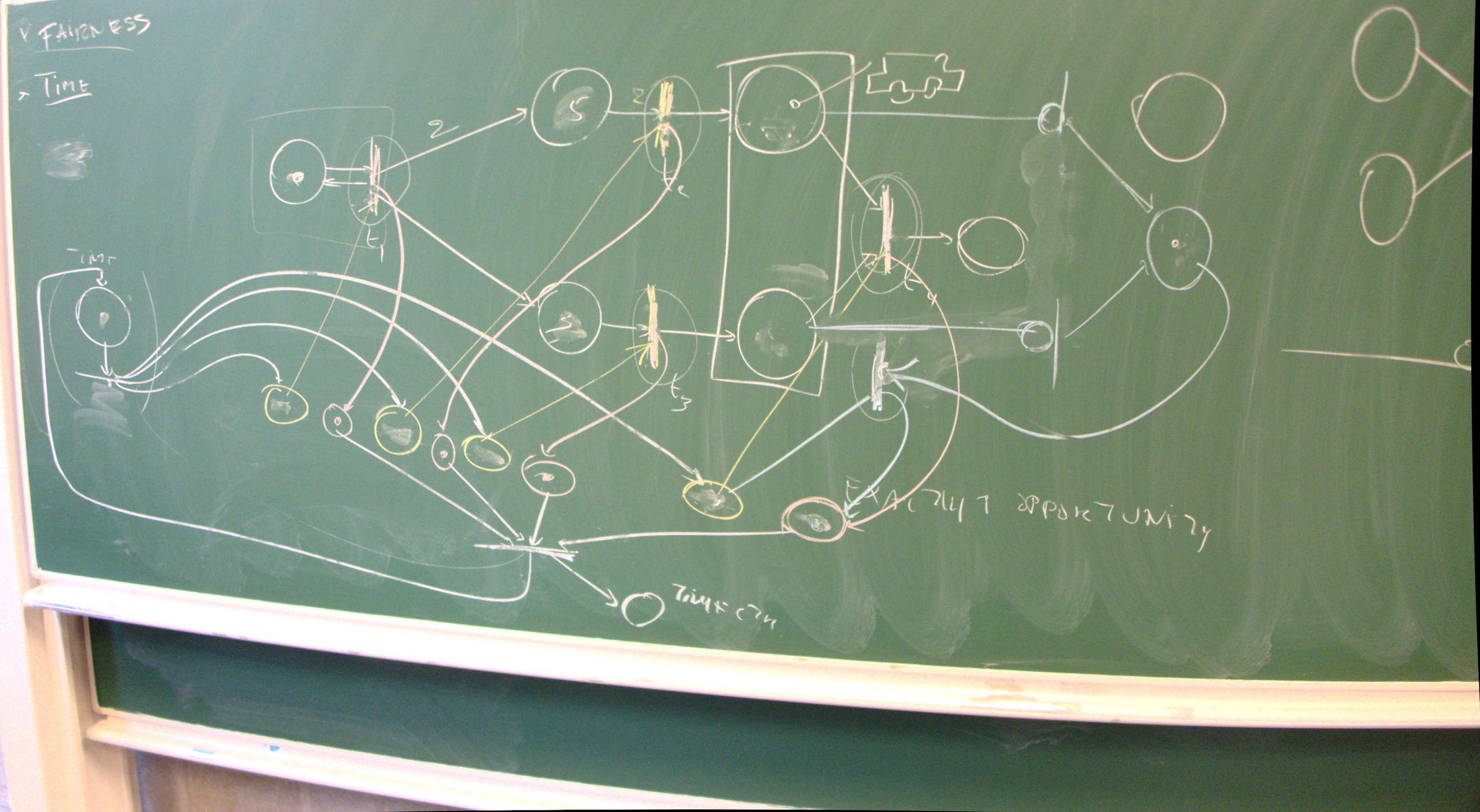
N K K·N


phi
pos



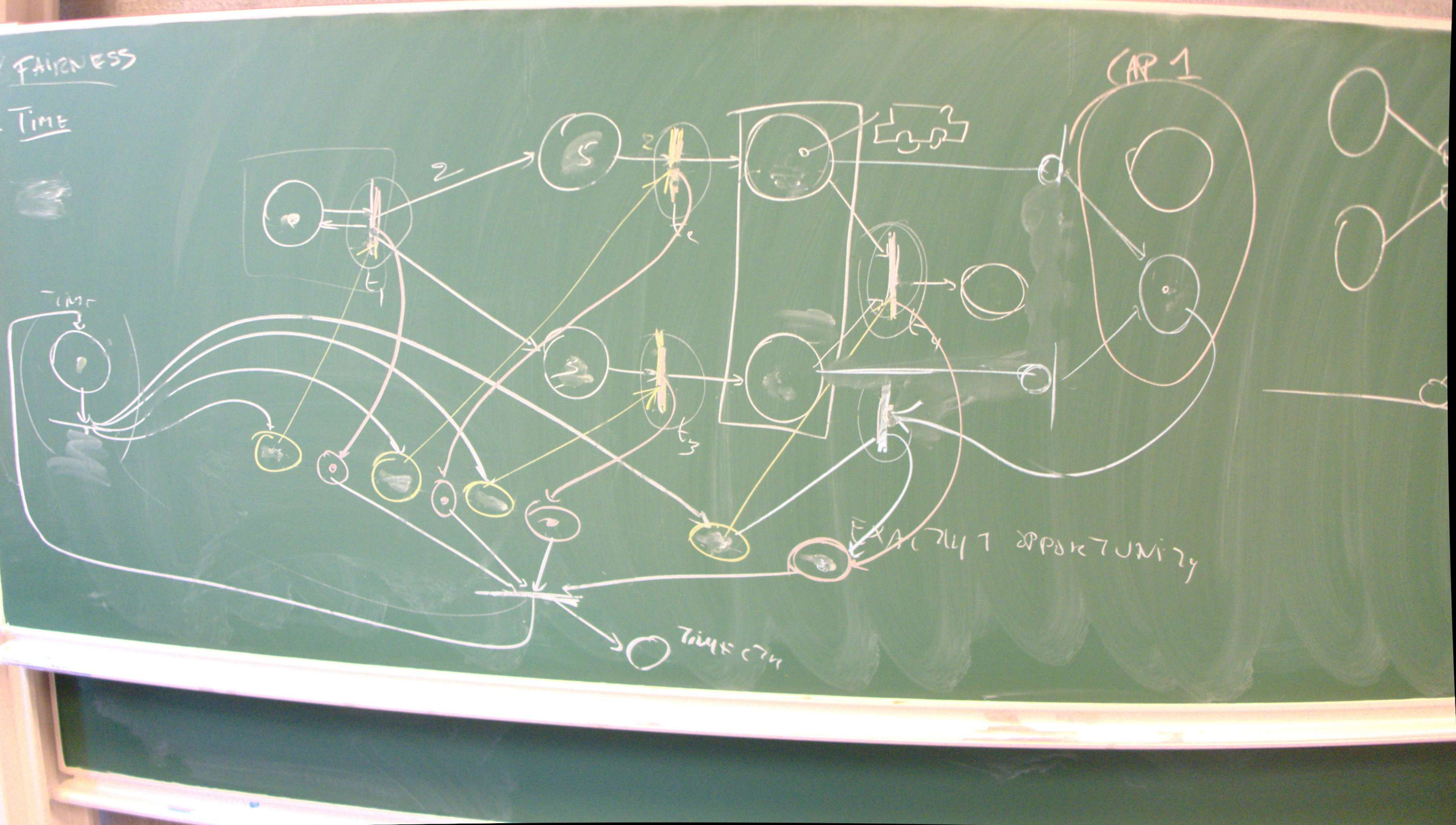
FAIRNESS

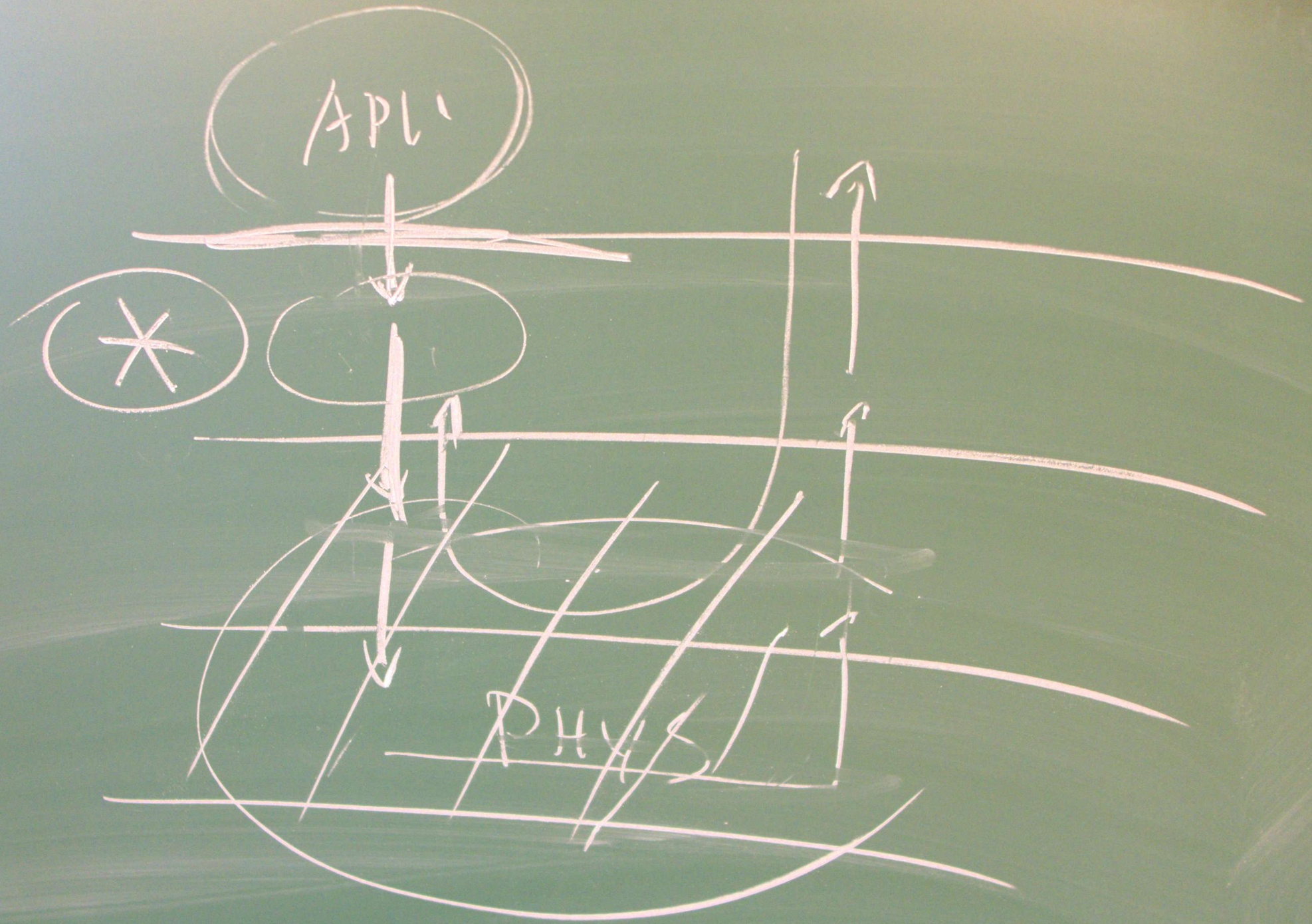
TIME

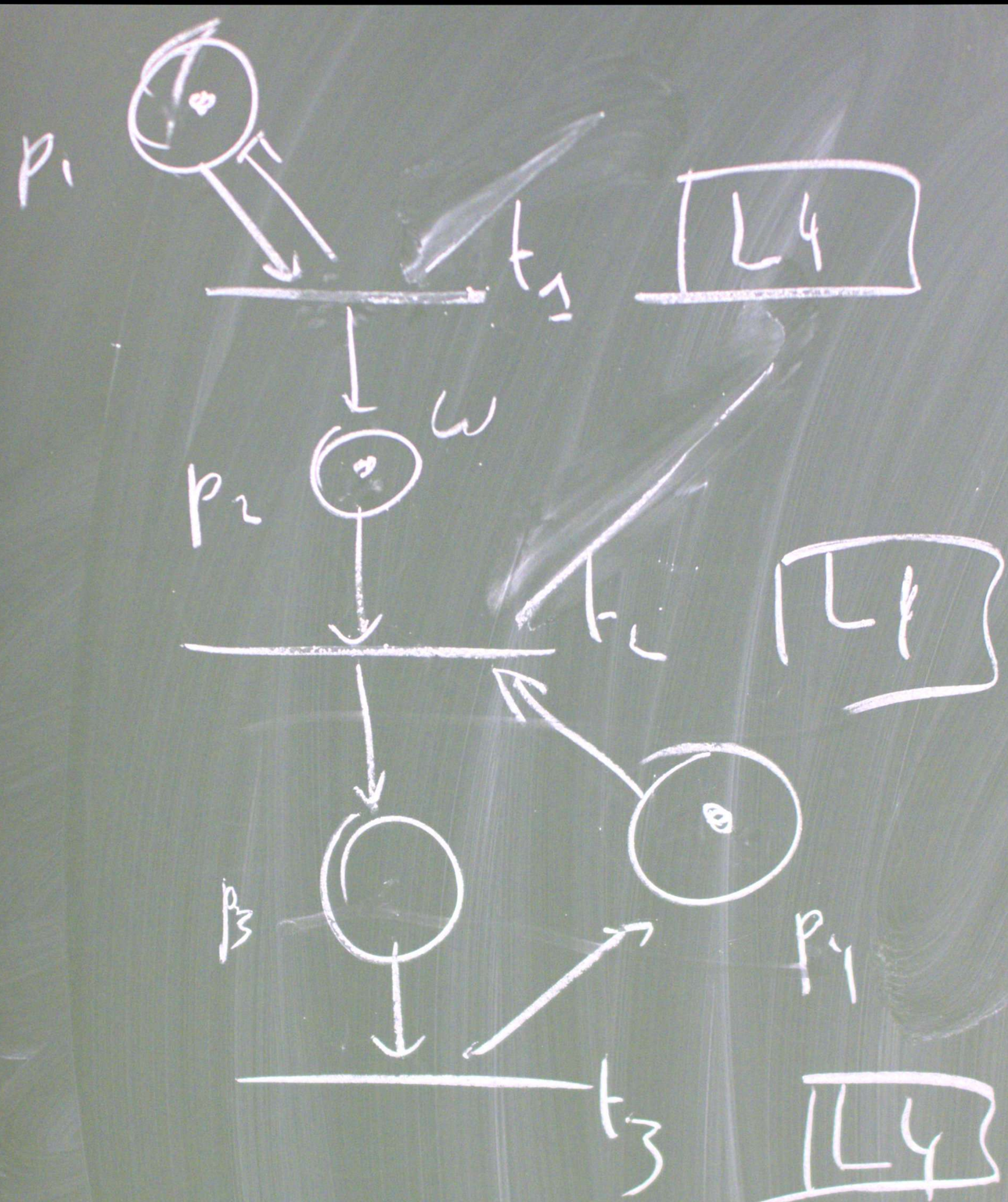


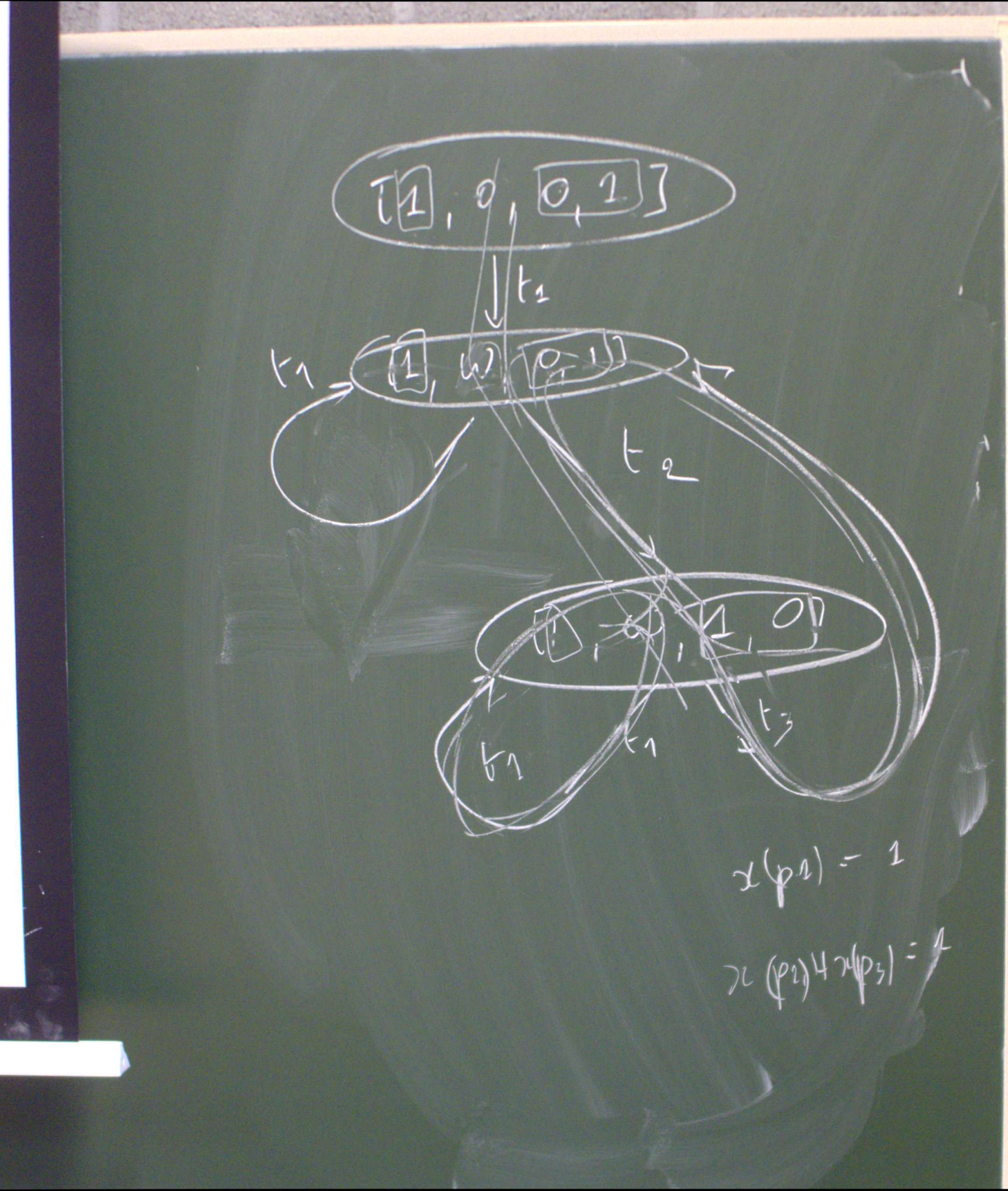
FAIRNESS

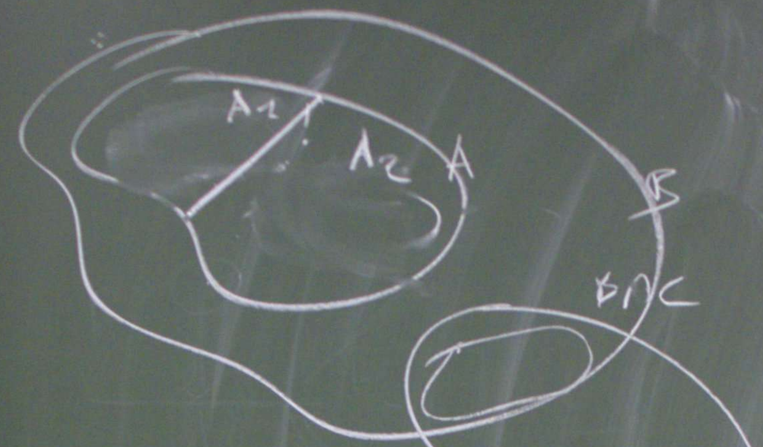
- TIME

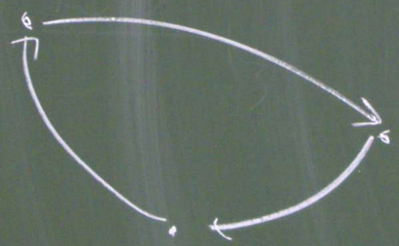


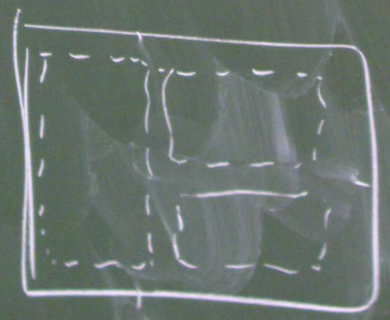

API
*
PHYS


p_1
t_1
L4
p_2
ω
t_2
L4
p_3
t_3
L4
p_4


[1, 0, 0 1]
t1
[1, 0, 0 1]
t1
t2
t3
t1
t1
x(p1) = 1
x(p2) + x(p3) = 1


A1
A2
A
B
B∩C
C
X





$A \otimes X = \{(a,b) \mid a \in A, \exists ! b \in B\}$

$A \subseteq B$

$B \cap C = \emptyset$

$\langle N, E \rangle$

$\subseteq N \times N$

$\subseteq \mathcal{P}(N) \times 2^N$

$(n_3, \{n_1, n_2\})$

(n_1, n_2)

$n_1 \quad e_1 \quad n_2$

$e_4 \quad e_2$

$n_4 \quad e_3$

STATECHARTS = HiGRAPHS + F

TIME

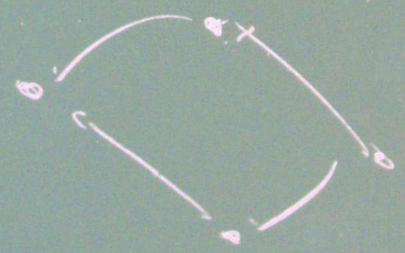
ALG

DT

CT

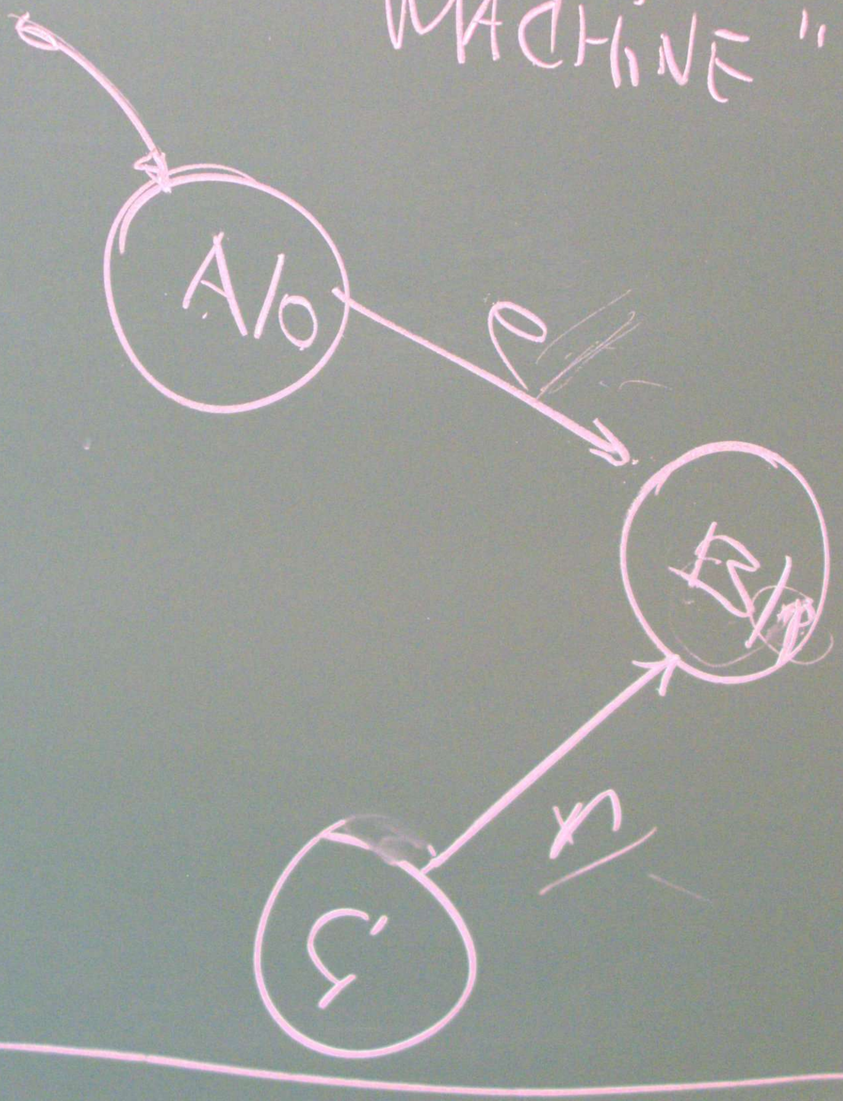
PN

DEV



DEV

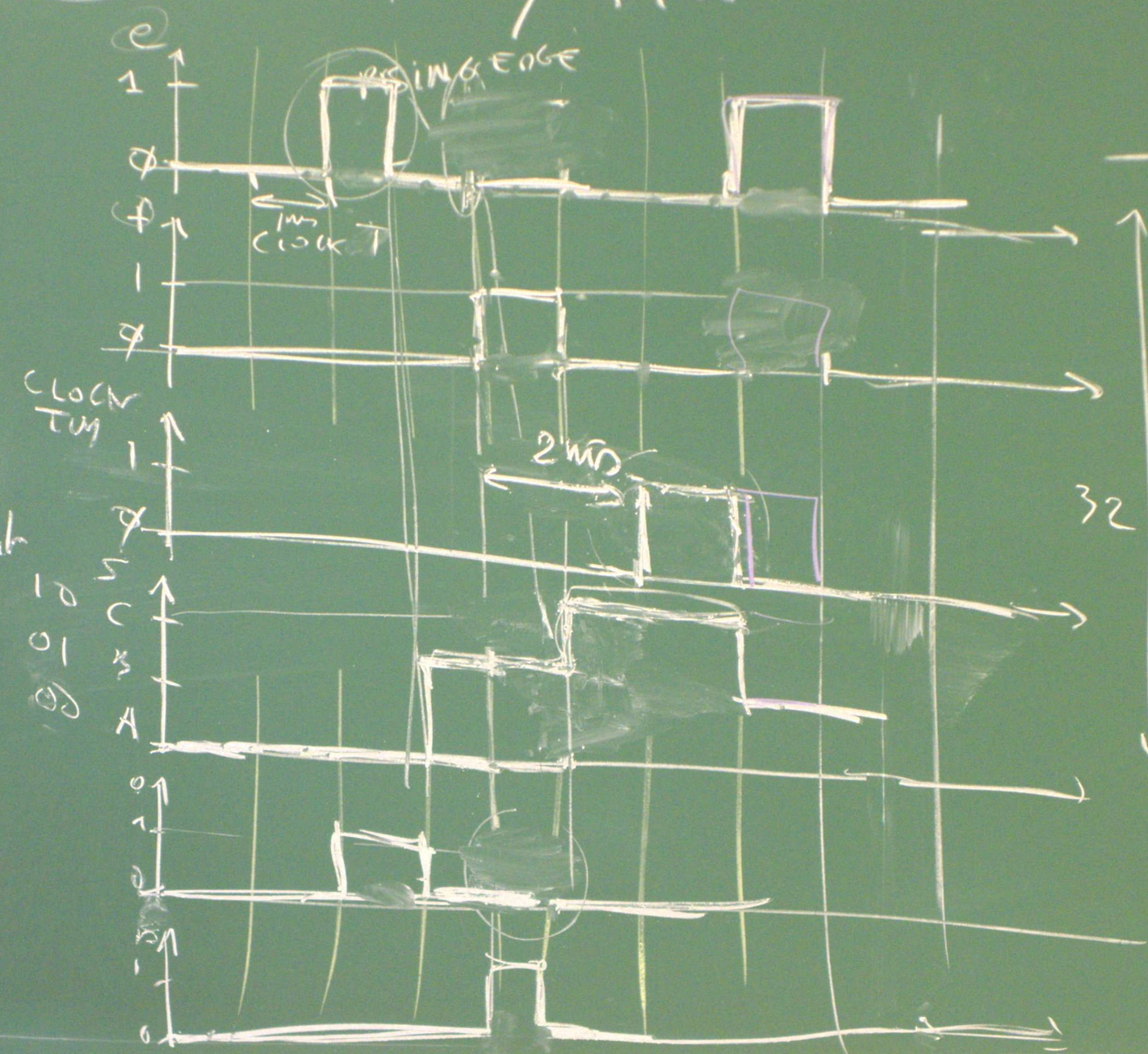
"MEALY MACHINE"



"MOORE MACHINE"


"MOORE"
MACHINE"
A
B
C
e / O
e
f / P
f
TIMED AUTOMATON
REACTIVE
AUTONOMOUS TIMED
MODEL
AFTER (2ms)
TM
DEV(S)
"LIGITIMATE"
X
f
e
1ms
2ms
S
C
B
A
Y
P
O

(I) DT / DIGITAL HW



TRUTH TA

e f tm

0 0 0
0 0 0
0 0 0

32

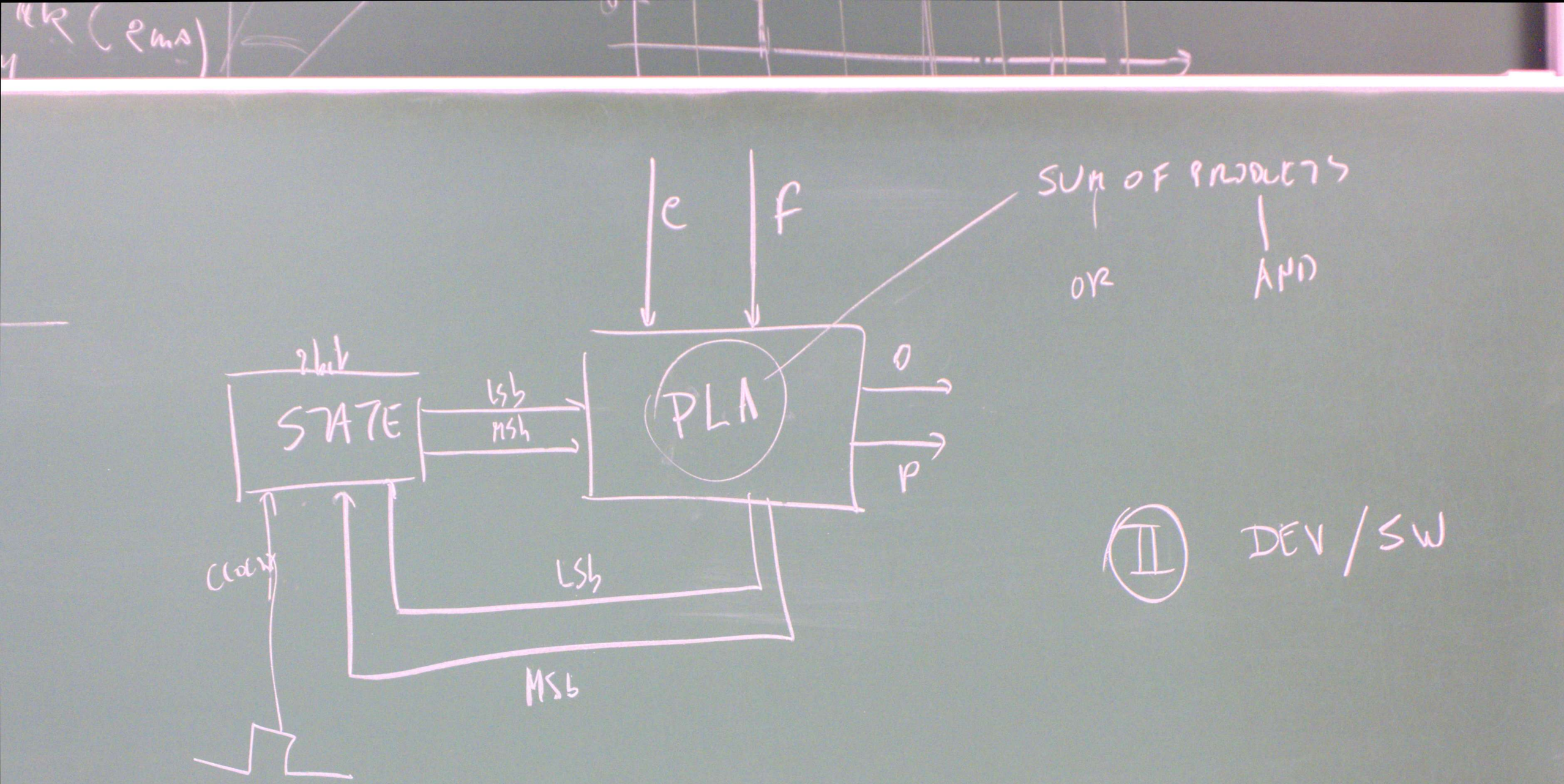
TRUTH TABLE

e	f	tm	S_LSb	S_MSb	S_LSb	S_MSb	o	p
0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	1	0	0
0	0	0	1	0	1	0	0	0

BEFORE ← | → AFTER

Vt DISCRETE

32



II DEV/SW


II. CT/DEV SW
currstate = "A"
time = ϕ
var1 = ϕ
var2 = 20
(ENUM TYPE)
EVENT HANDLER
def e( ):
switch currstate:
case "A":
produce output o
currstate = "B"
case "C"
currstate = "A"
o( )
"STORE"
VAR1 ϕ
VAR2
MODAL
EVENT
ACTION CODE
e/o ; var2 := var1 + 2
"AND" "IF"
GUARD
[VAR1 + VAR2 > 10]
TOTAL STATE Q
TYPE(VAR1) × TYPE(VAR2) × TYPE(MODEL)
{A, B, C}
f/p
after(2ms)
COMPOSITE/SUPER STATE
ATOMIC STATE BASIC
INNER
OUTER
ENTER
EXIT

(AFTER(VARIABLE)

NORMAL

MODAL

STATE

ENTER: A

EXIT:

@ [guard] / OUTPUT:
- EVENT-
- ACTION

WHEN @ AND GUARD

IF GUARD BECOMES TRUE

B

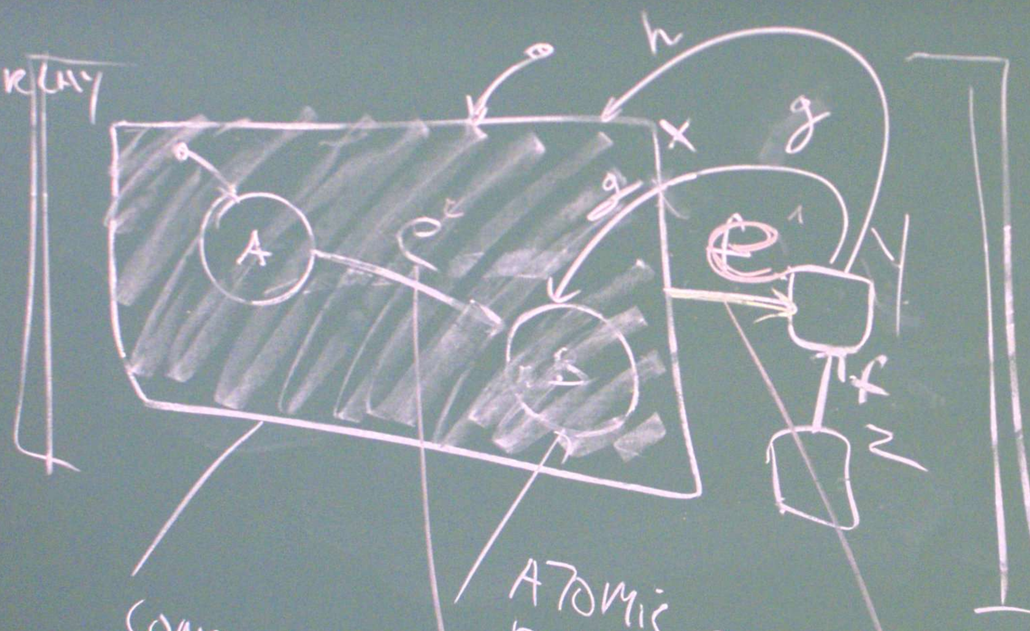
R2) X TYPE(MODE)

{A, B, C}

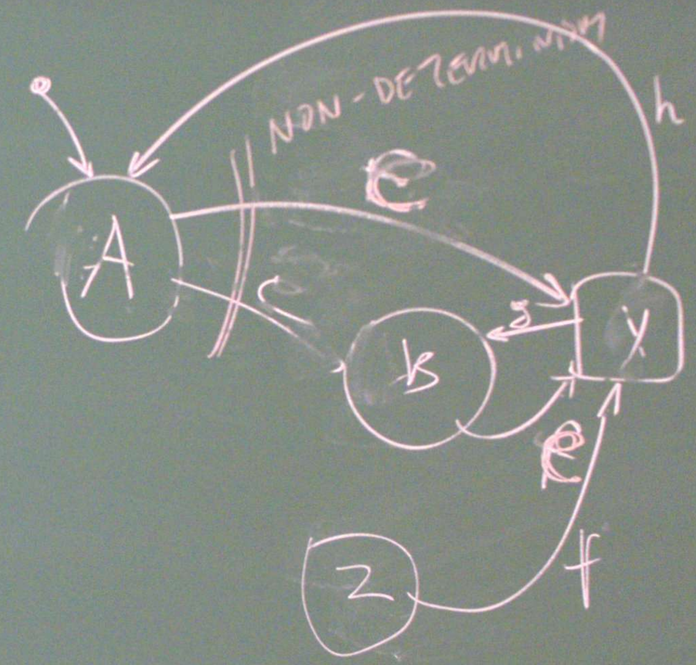
module = 'A"

STATECHARTS = HiGRAPHS + FSA + TIME

HIERARCHY



=



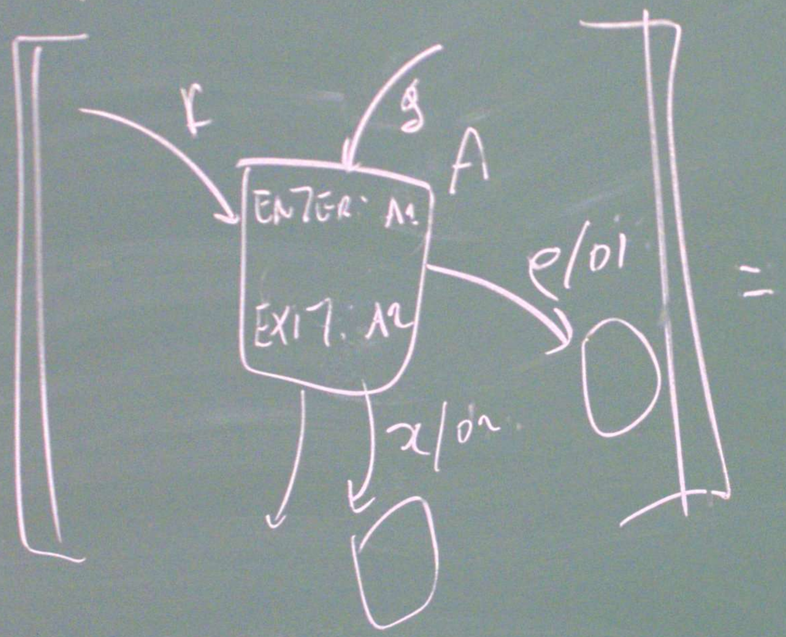
COMPOSITE/ SUPER STATE

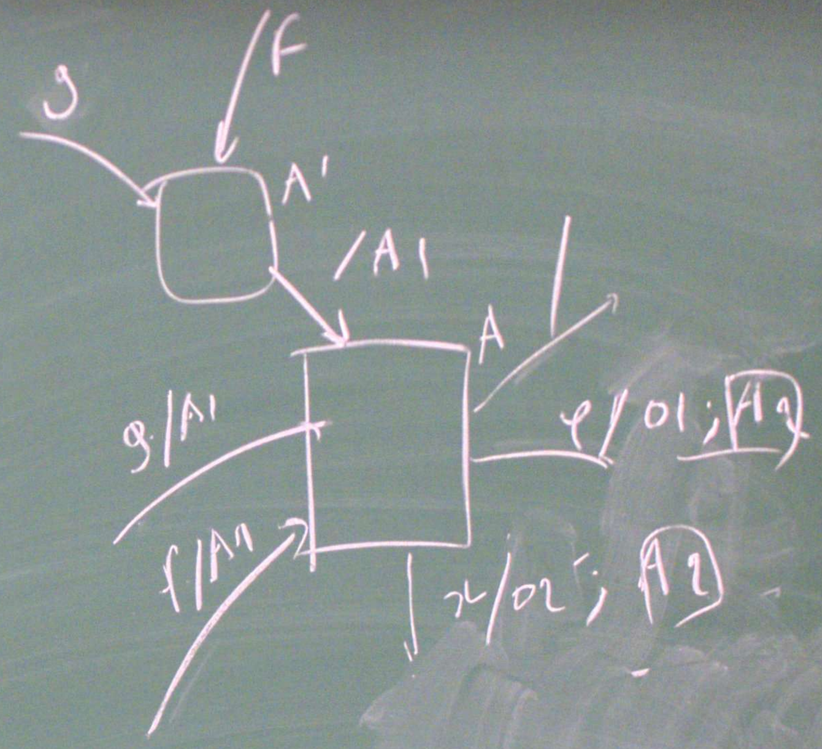
ATOMIC BASIC STATE

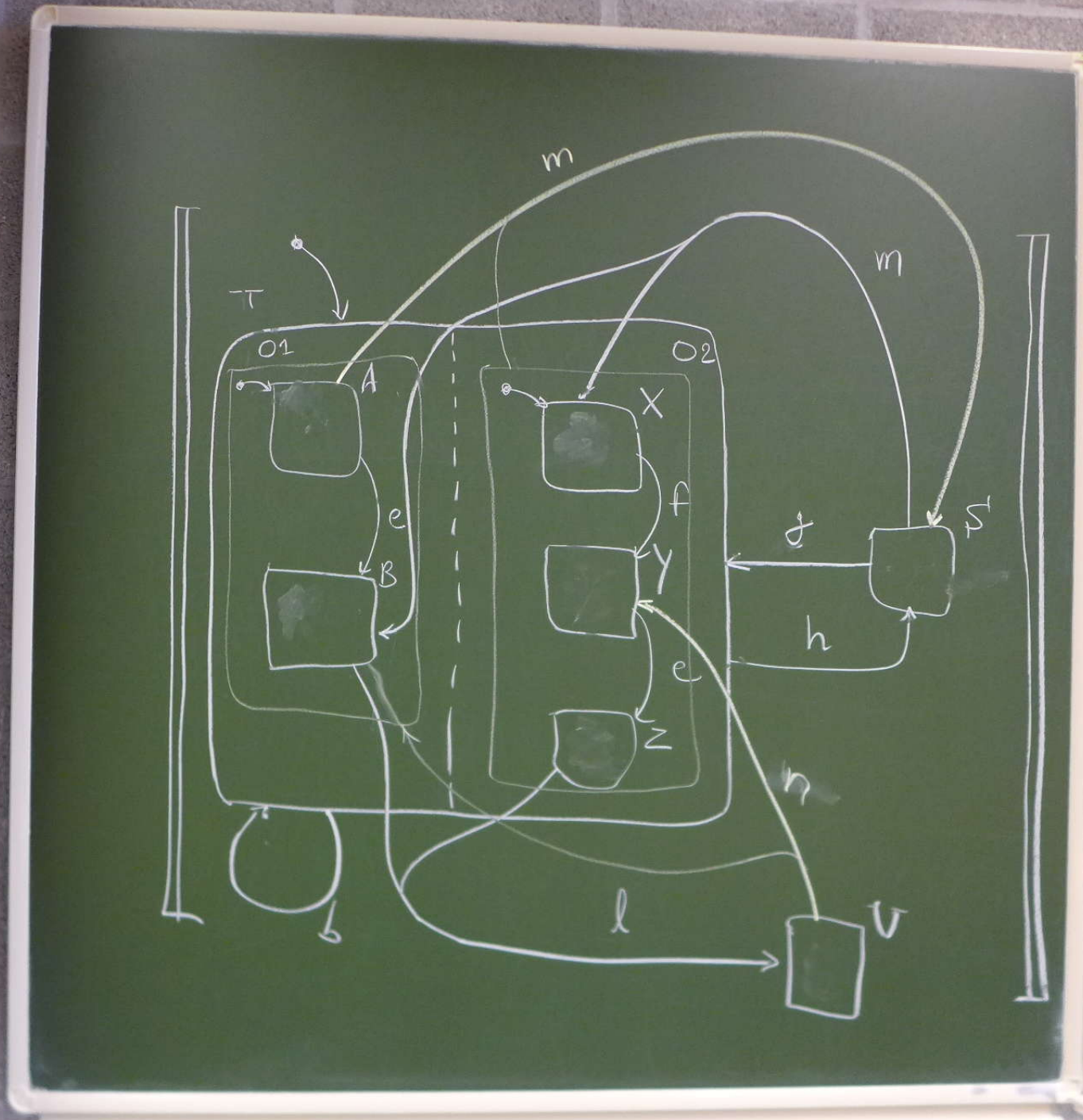
INNER UML RHAPSODY

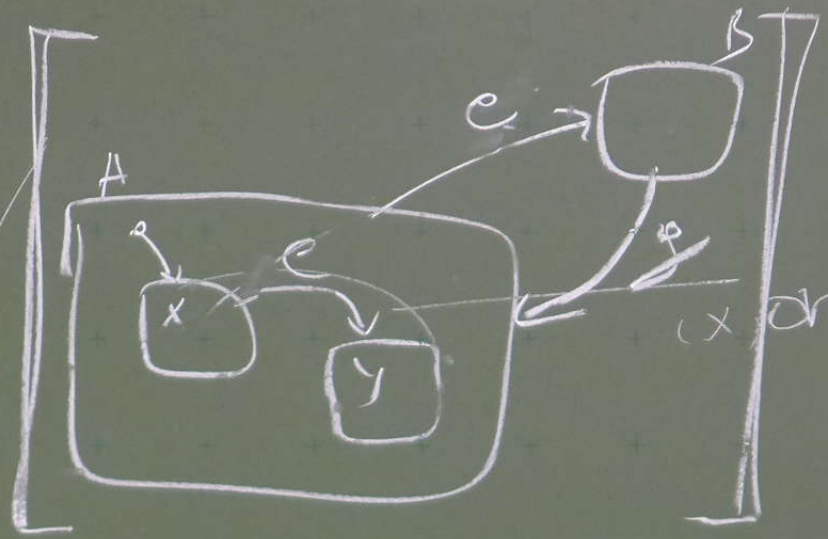
OUTER HAREL STATEMATE

ENTER/EXIT ACTIONS
ARE SYNTACTIC SUGAR

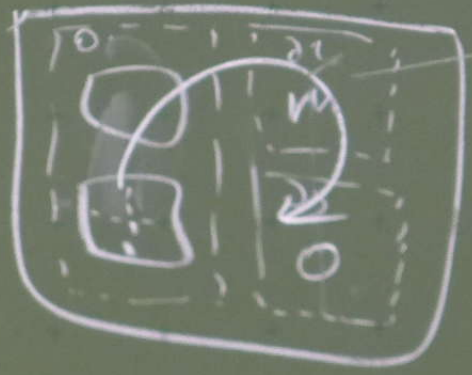





m
m
T
O1
O2
A
X
e
f
g
S
B
Y
h
e
Z
n
l
V

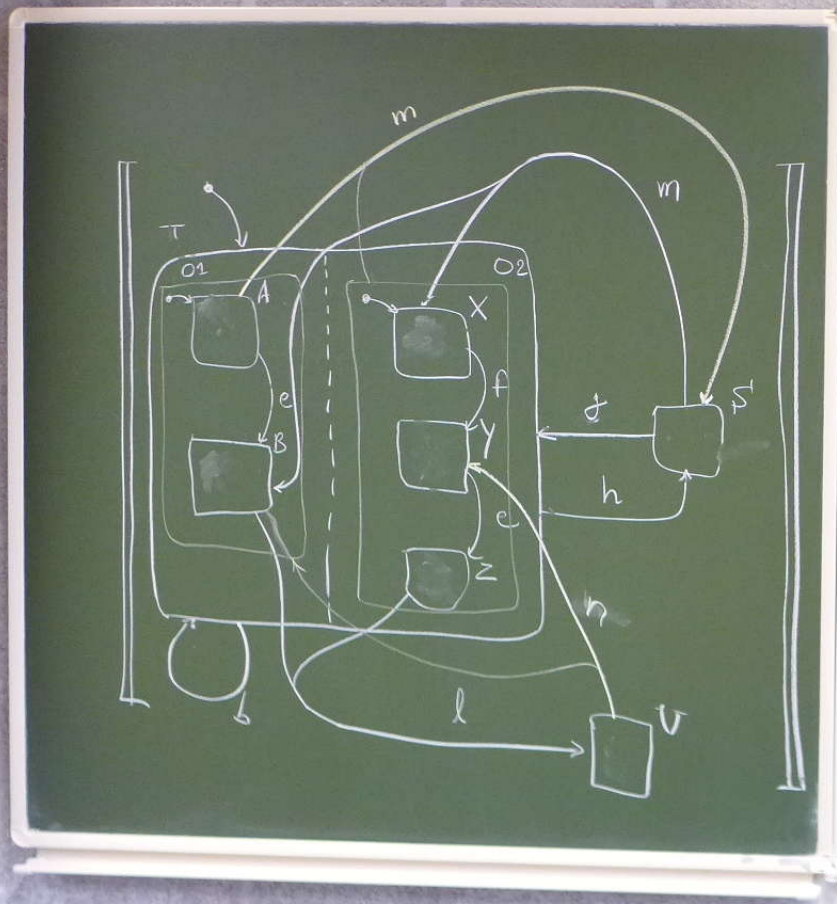


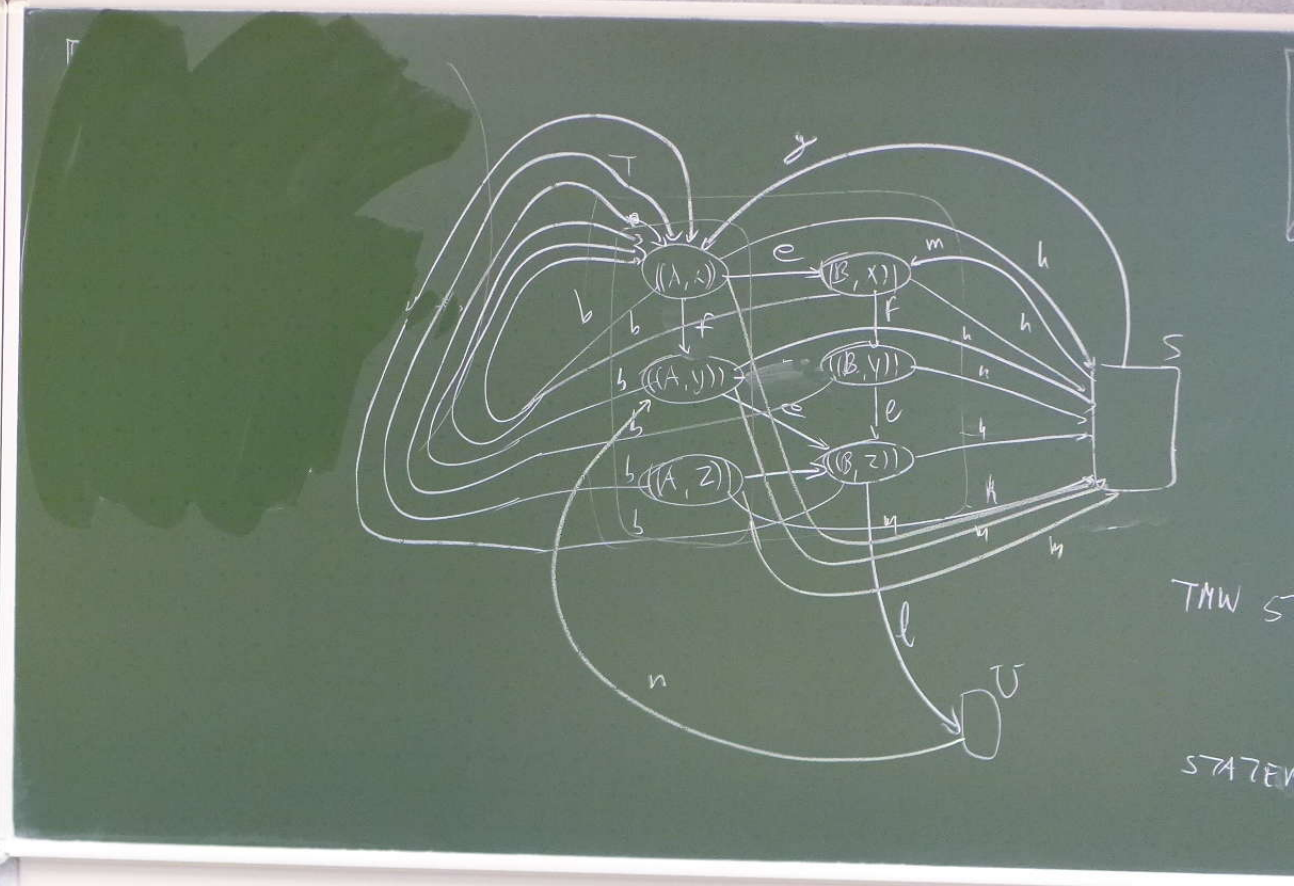
OR - STATES

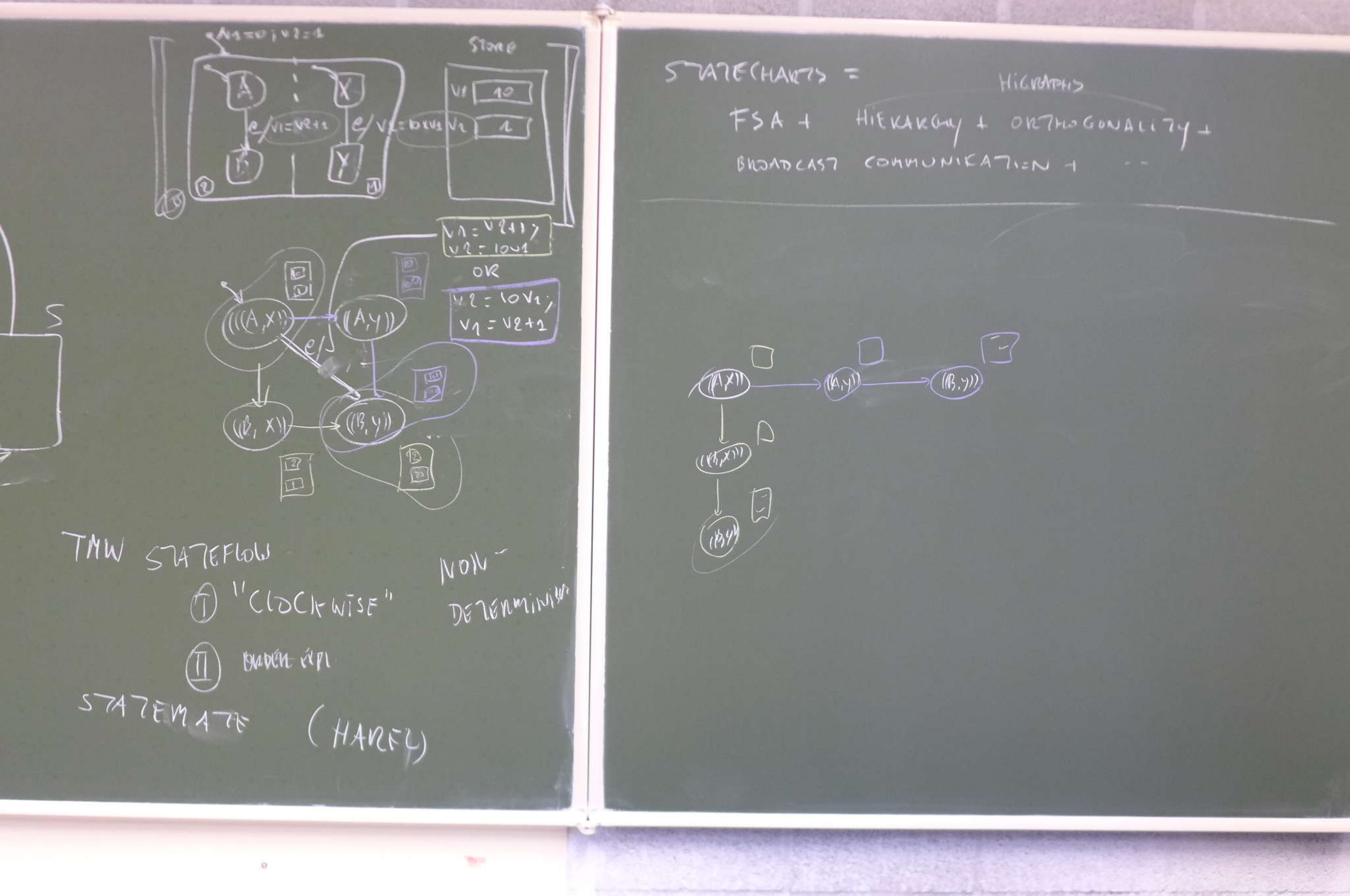


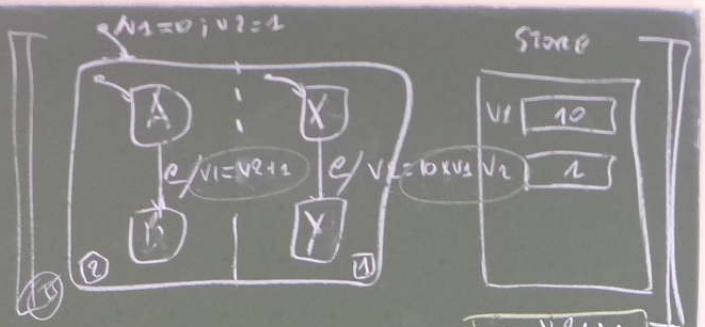
AND STATES

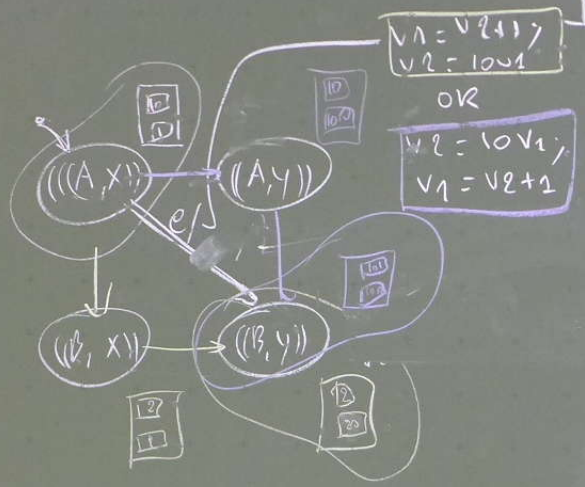
N × M × O


T
O1
O2
A
B
X
Y
Z
e
f
g
h
m
n
l
S'
U


T
g
e
m
h
b
f
F
S
l
n
U
TMW


Store
v1 = v2+1;
v2 = 10v1
OR
v2 = 10v1;
v1 = v2+1
TMW STATEFLOW
(I) "CLOCKWISE"
NON-DETERMINISM
STATEMATE (HAREL)
STATECHARTS =
HIGRAPHS
FSA + HIERARCHY + ORTHOGONALITY +
BROADCAST COMMUNICATION + ...





TMW STATEFLOW

① "CLOCKWISE"

② BUDEN KÉPI

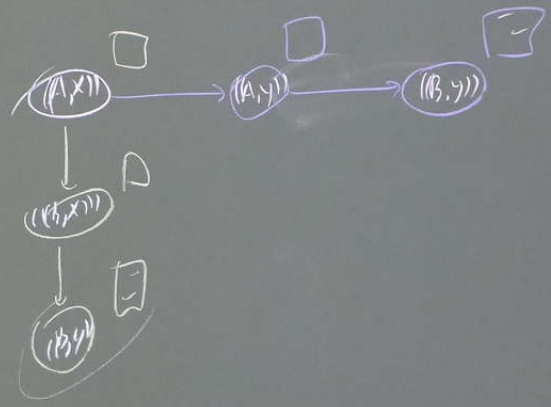
NON-DETERMINISM

STATEMATE (HAREL)

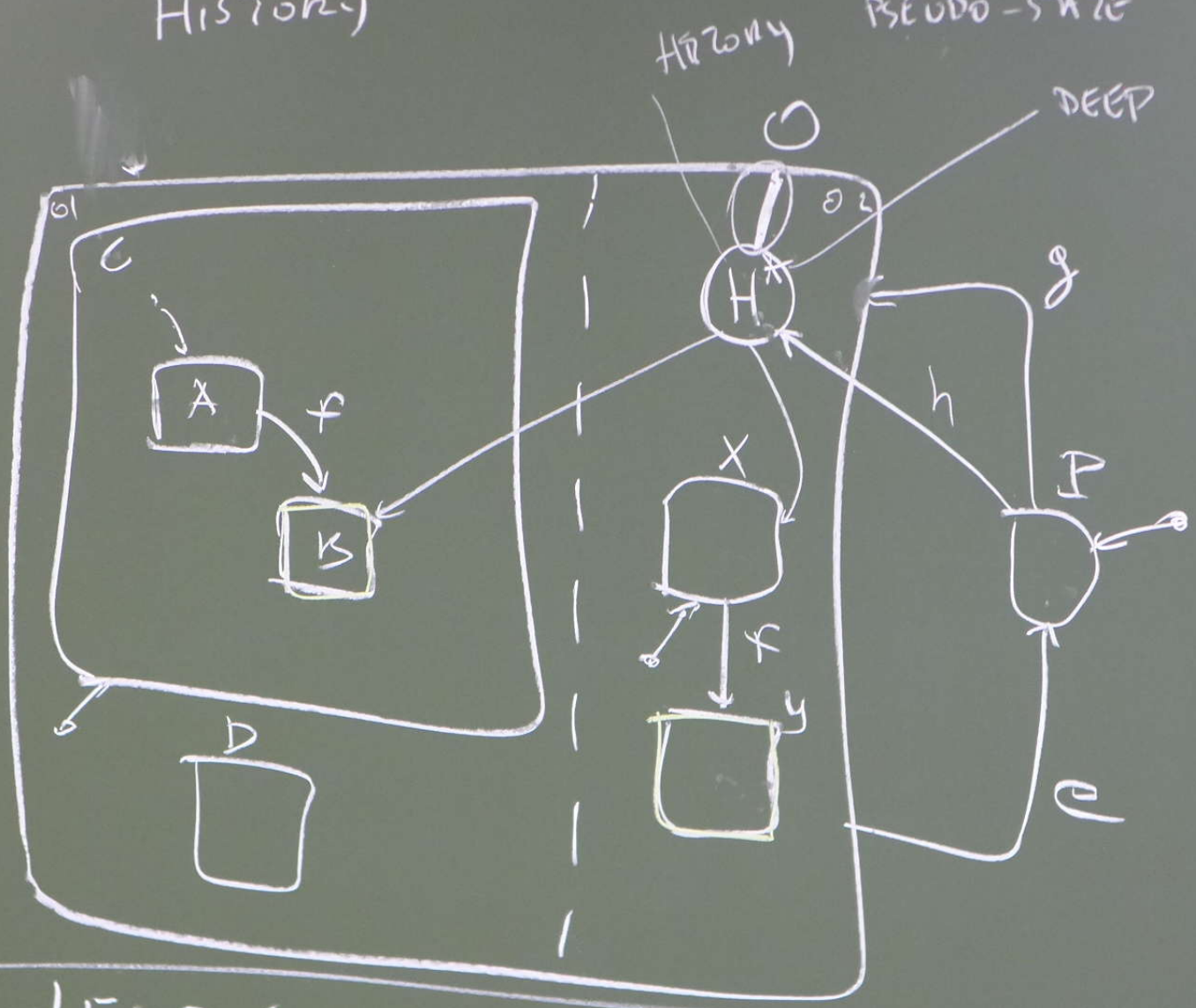
STATECHARTS = HIGRAPHS

FSA + HIERARCHY + ORTHOGONALITY +

BROADCAST COMMUNICATION + ...



(H) History

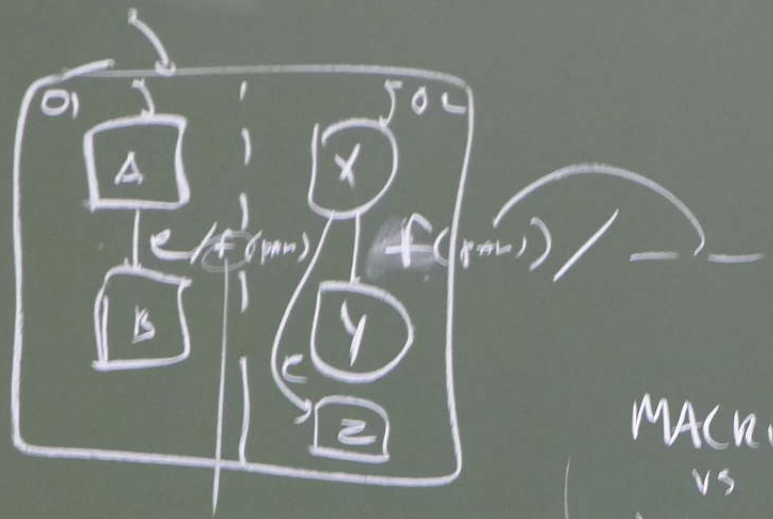


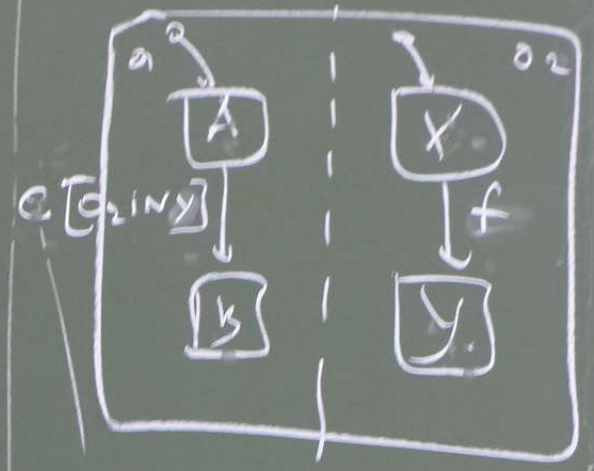
LCA LEAST COMMON ANCESTOR

À EXIT

BROADCAST COMM.

STATE REF.





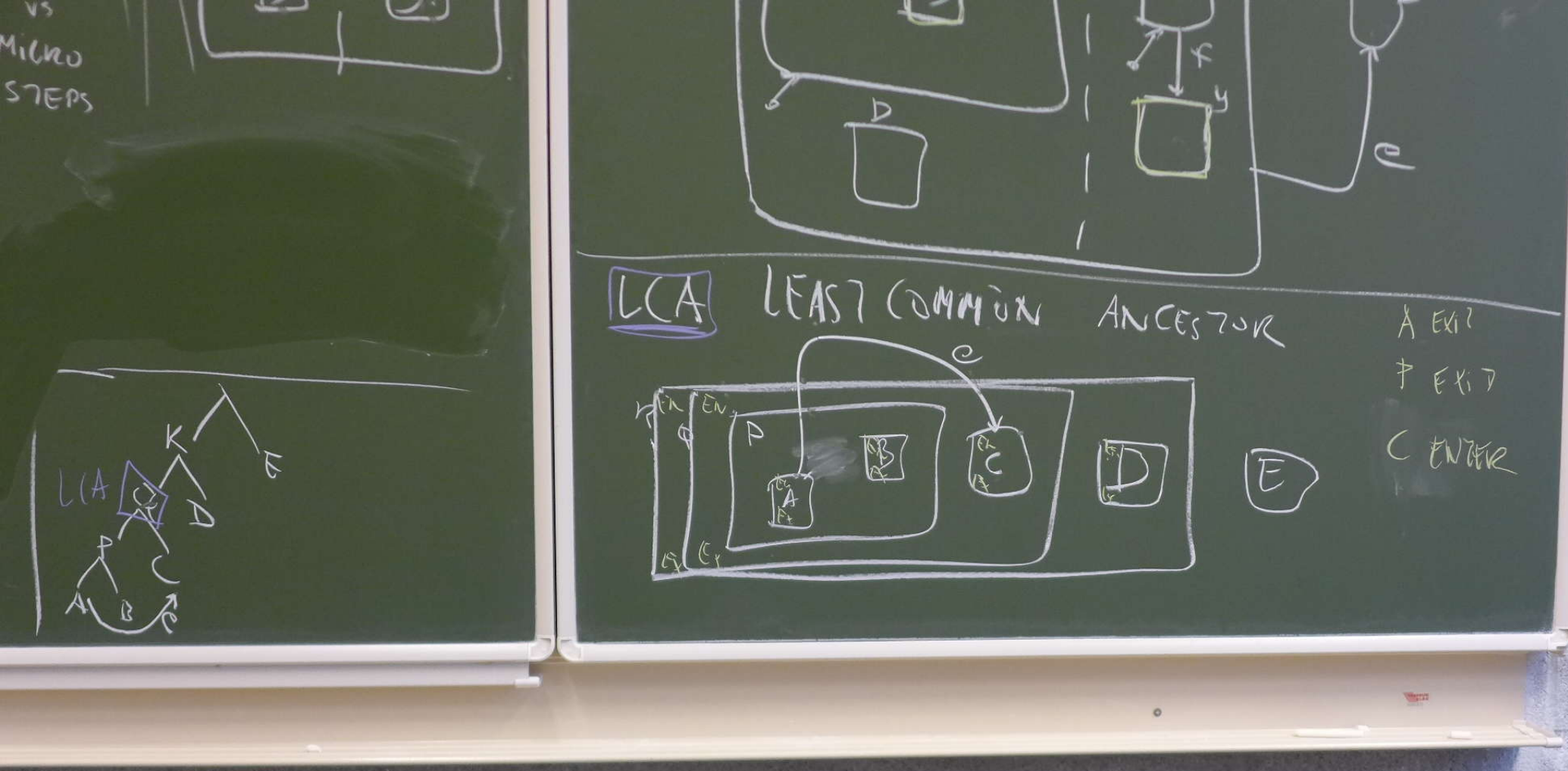
MACRO
vs
MICRO
STEPS

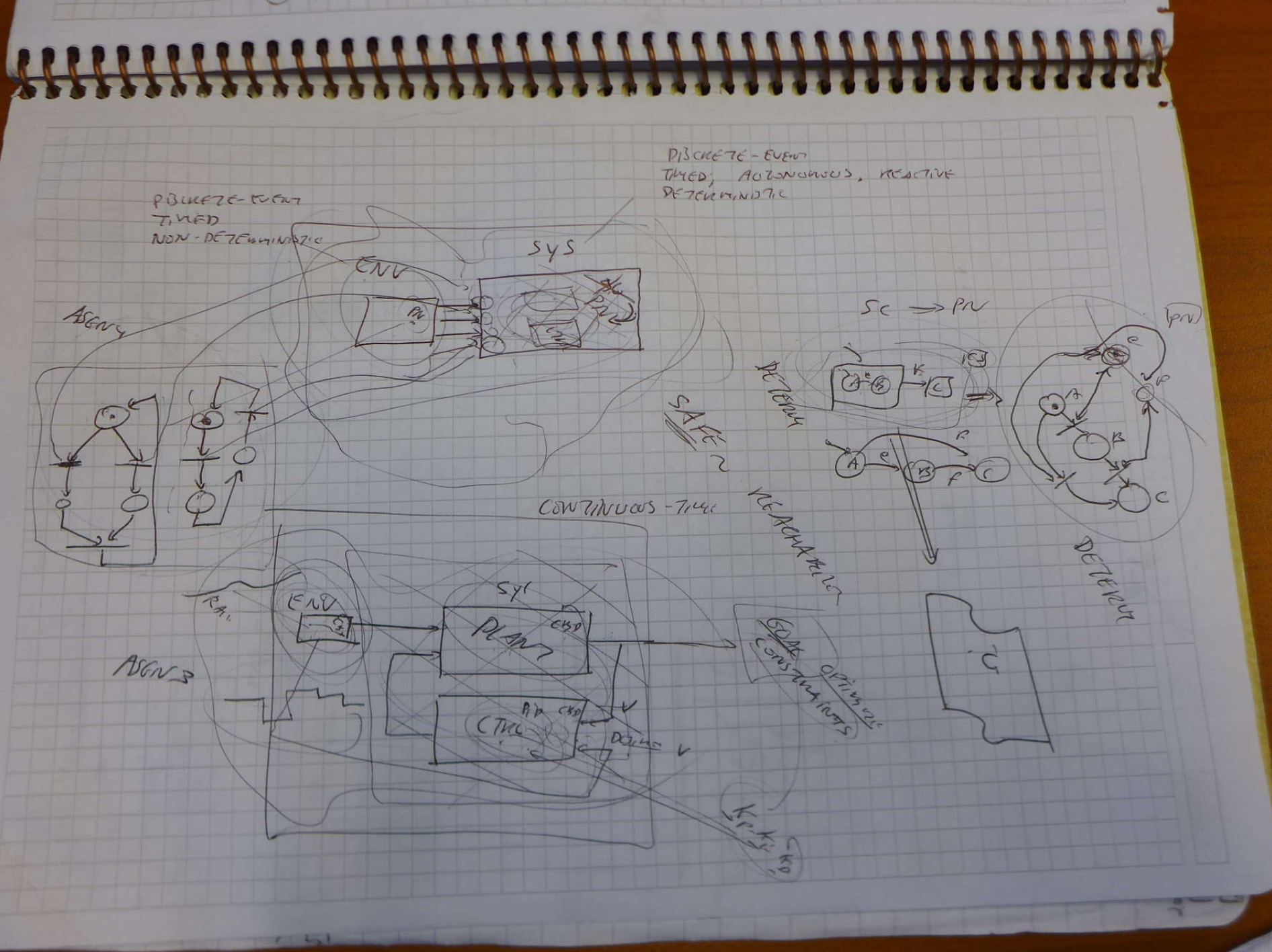
"BROADCAST"

"NARROW CAST"

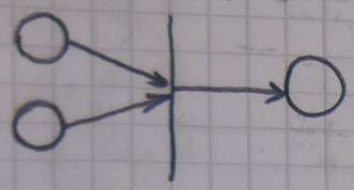
WHEN e AND
IF [ ]

WHEN [ ]
BECOMES TRUE

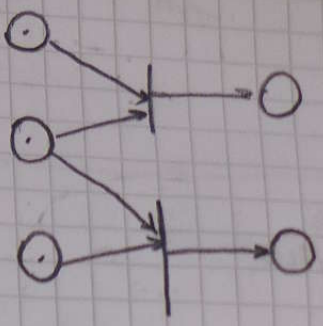

LCA
LEAST COMMON ANCESTOR
A EXIT
P EXIT
C ENTER
LCA
K
E
D
P
A
B
C


DISCRETE-EVENT
TIMED
NON-DETERMINISTIC
ENV
SYS
AGENTS
DISCRETE-EVENT
TIMED, AUTONOMOUS, REACTIVE
DETERMINISTIC
SC ⇒ PN
DETERM
STATE
CONTINUOUS-TIME
REACHABILITY
DETERM
ENV
SYS
PLANT
CTRL
AGENTS
GOAL
CONSTRAINTS
OPTIMIZE
U

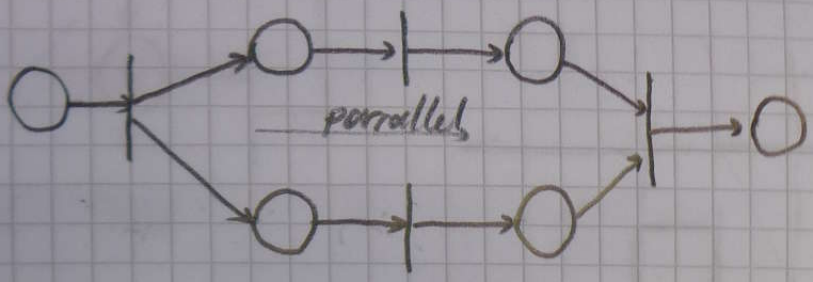
(join)



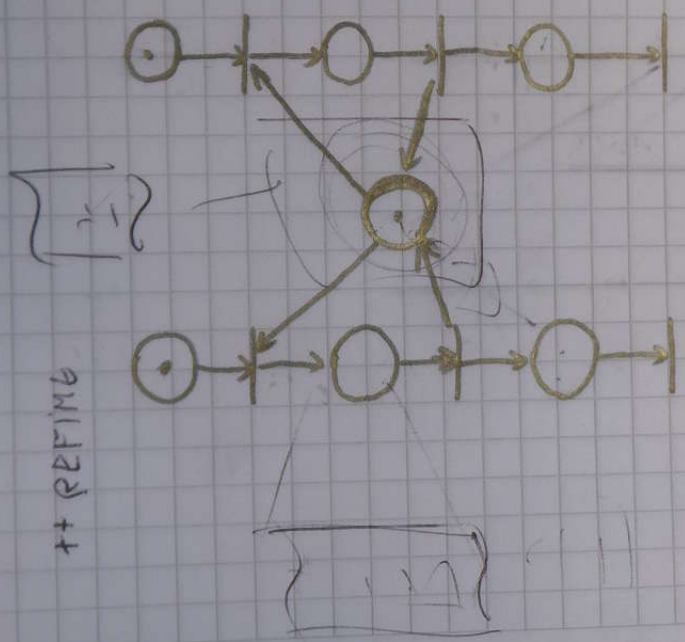
Conflict



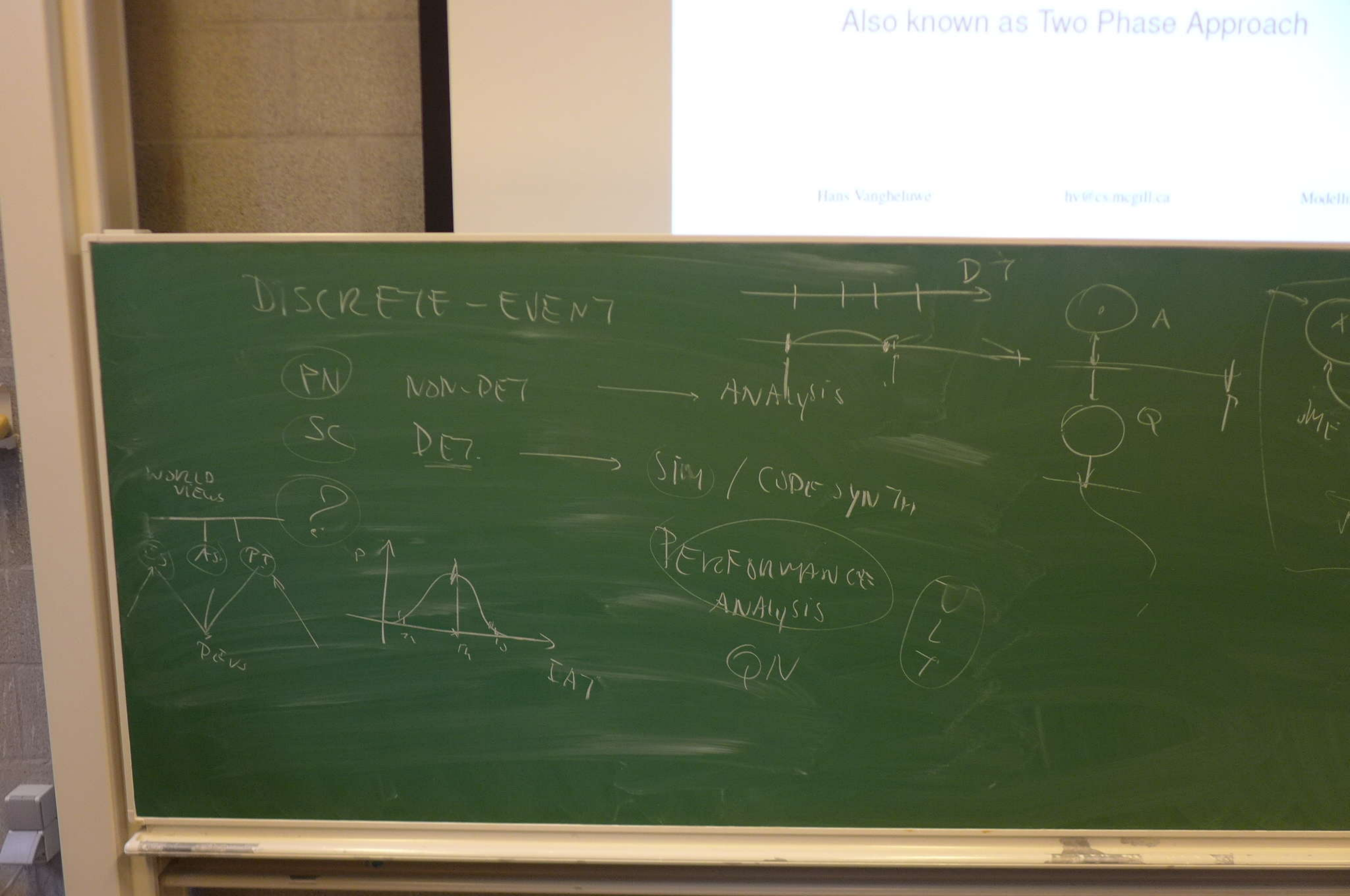
Concurrency

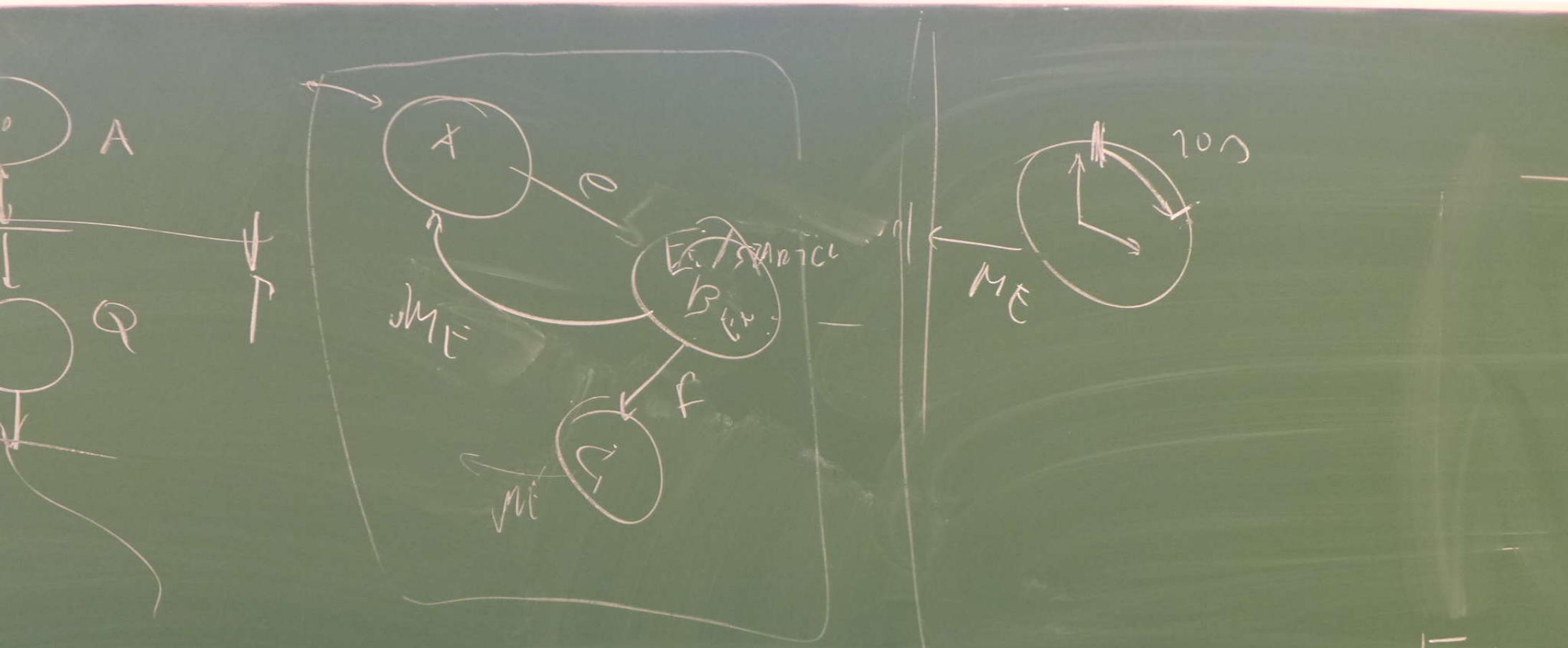


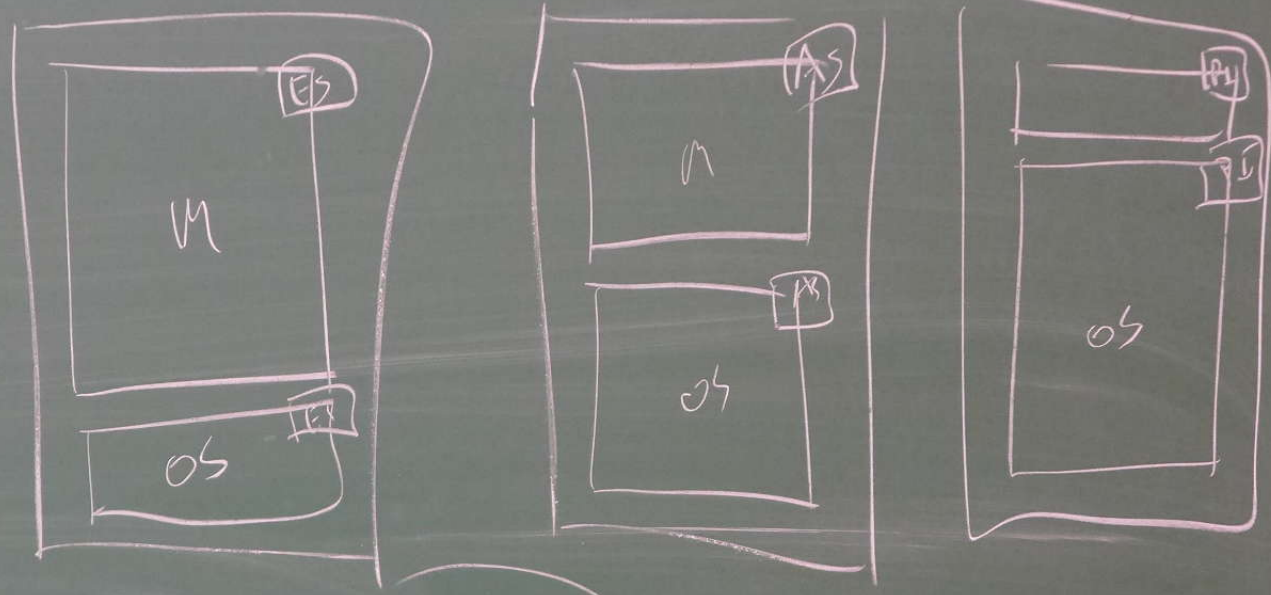
• Resource Sharing



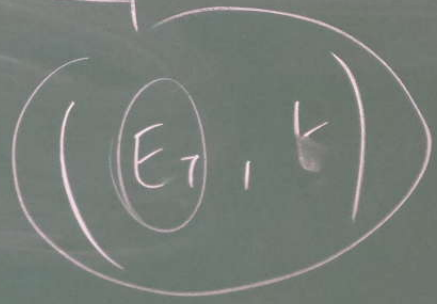
Now, we have conflict. th
can be solved by mute

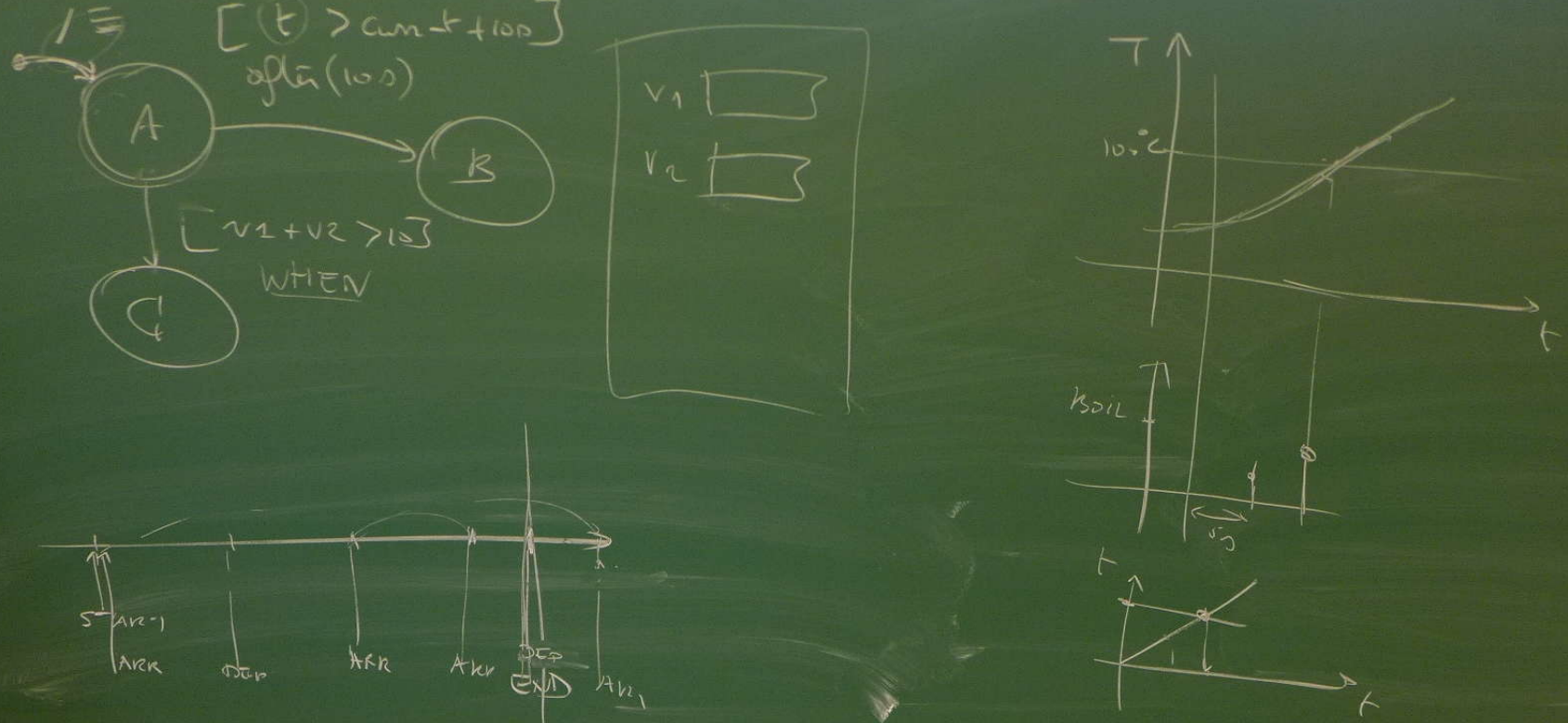

Also known as Two Phase Approach
Hans Vangheluwe
hv@cs.mcgill.ca
DISCRETE-EVENT
PN
NON-DET
ANALYSIS
SC
DET.
SIM
PERFORMANCE
ANALYSIS
QN
WORLD
VIEWS

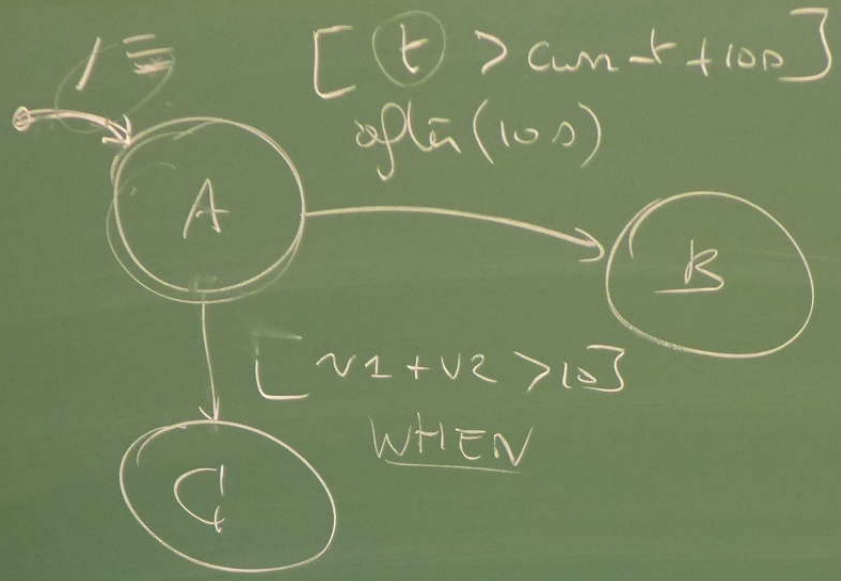

A
Q
e
f
EVEN

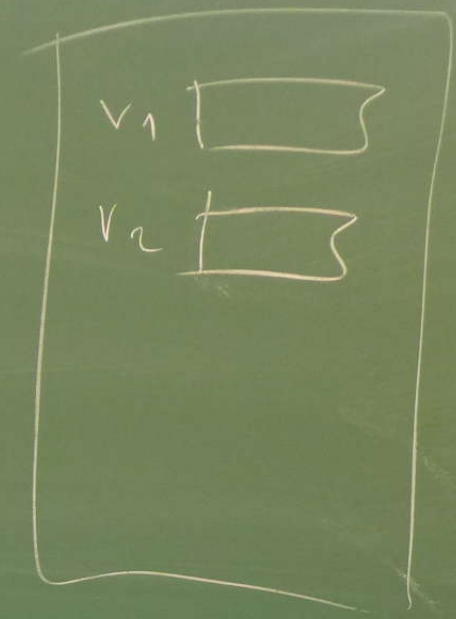


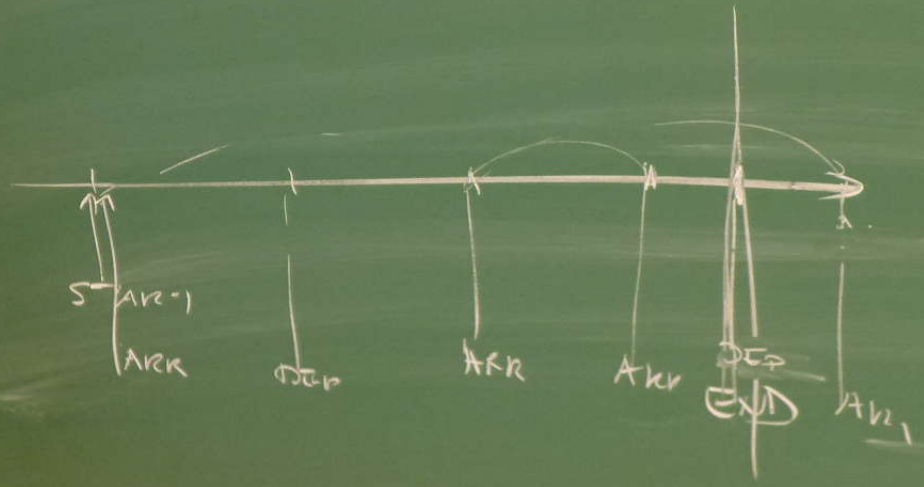
EVENT NOTICE

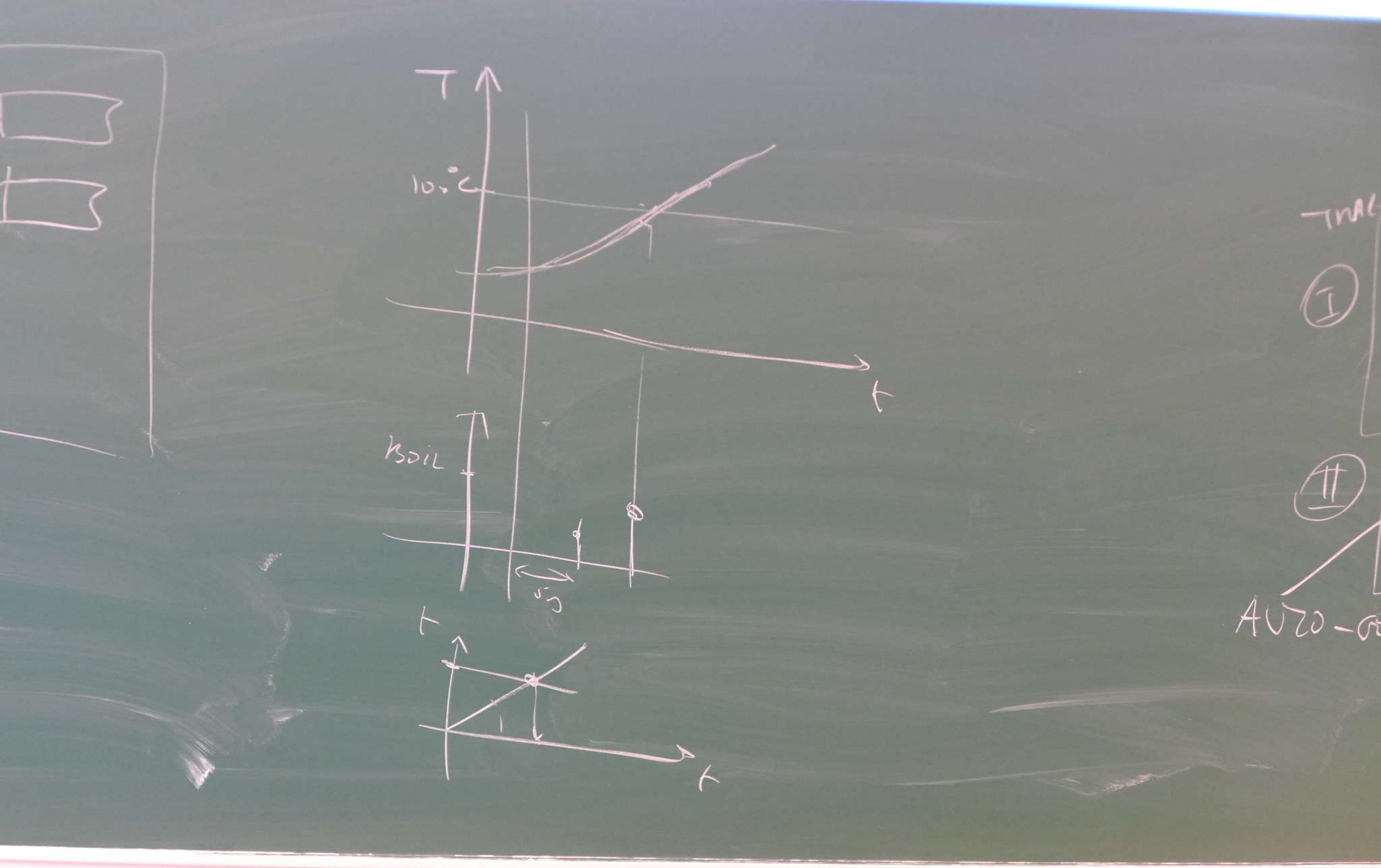


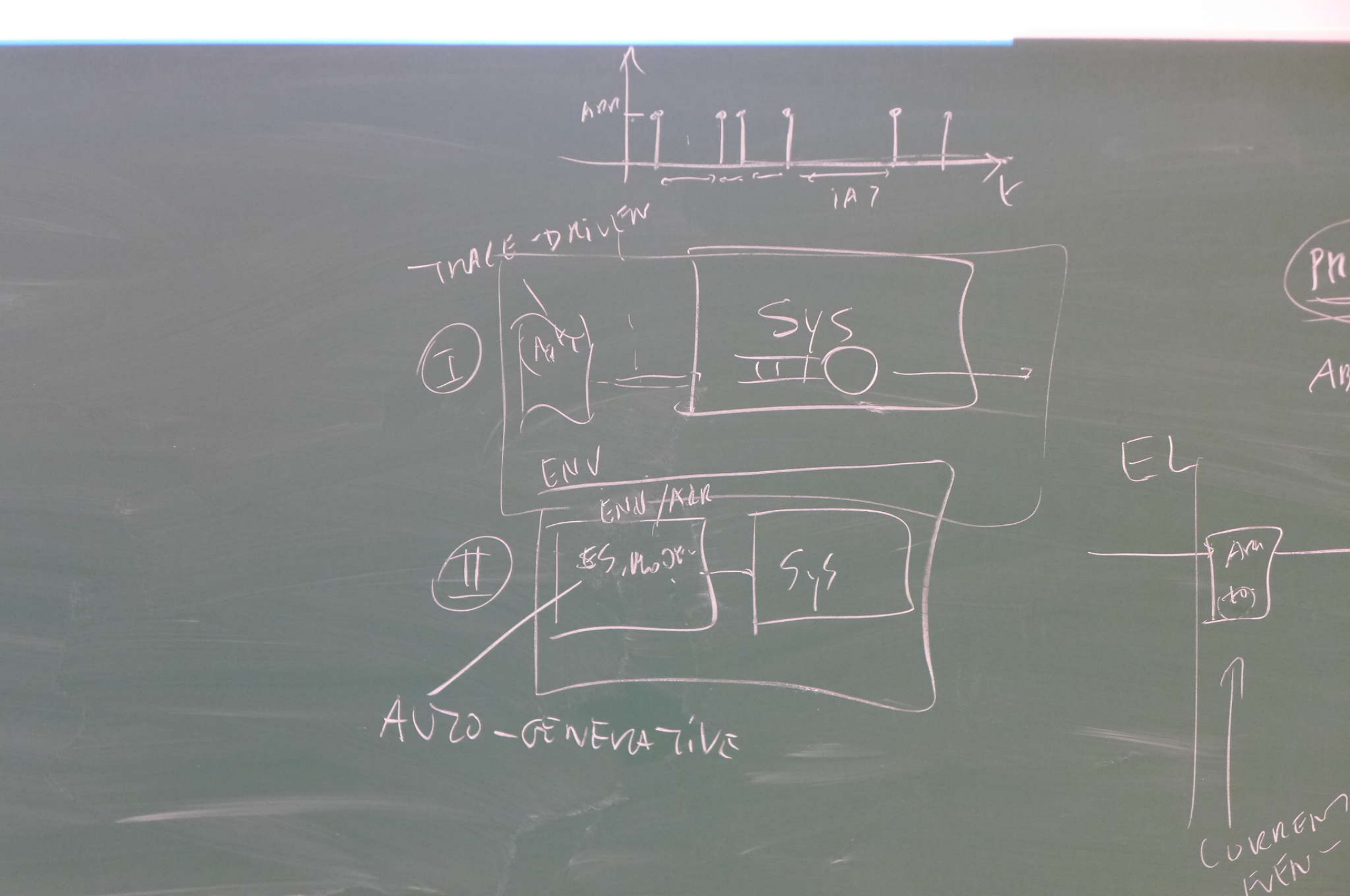

A
B
C
[t > curr_t + 100]
after(100)
[v1 + v2 > 10]
WHEN
v1
v2
T
10°C
t
T_SOIL
t
t

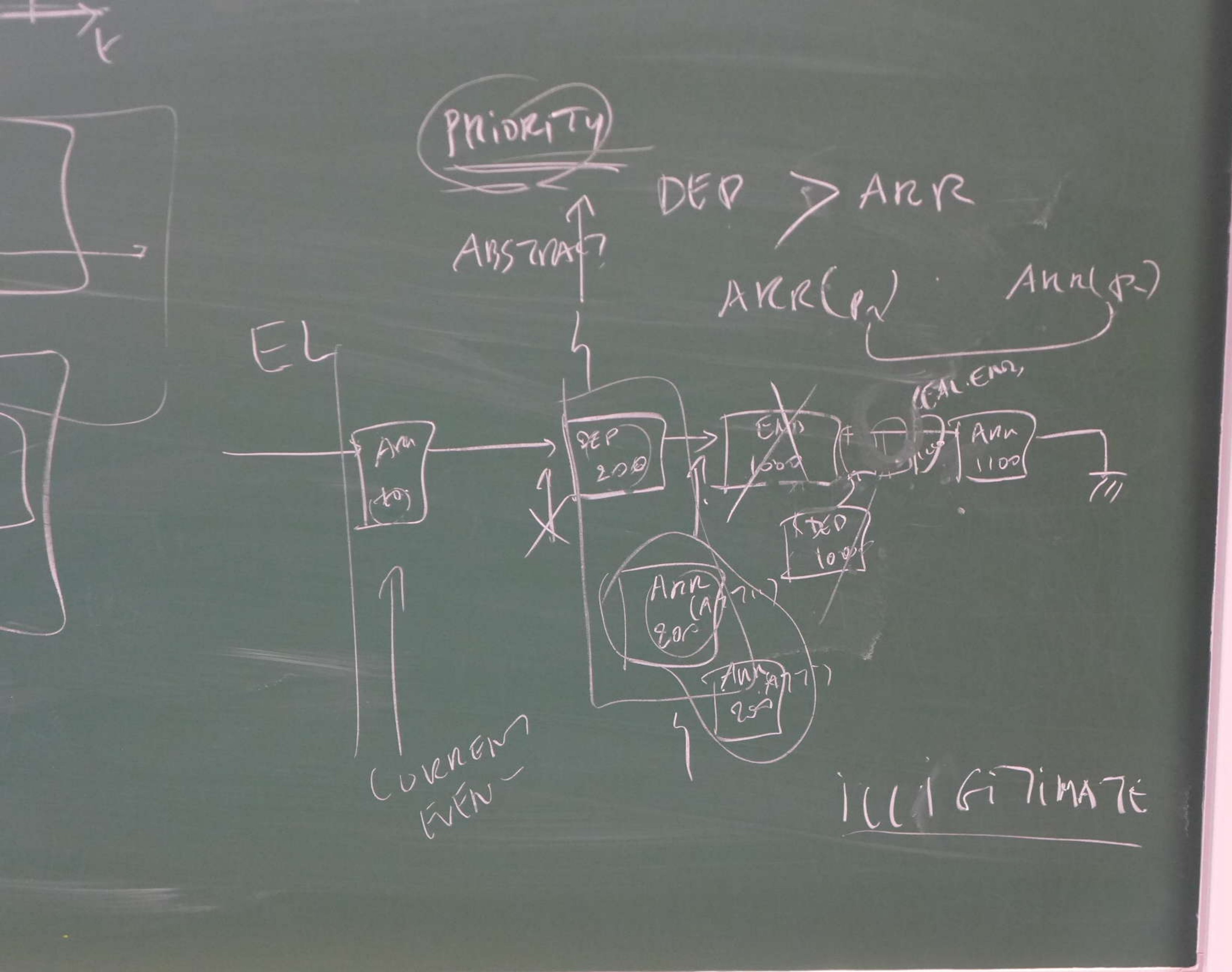

[t > curr_t + 10s]
after(10s)
A
B
C
[v1 + v2 > 10]
WHEN

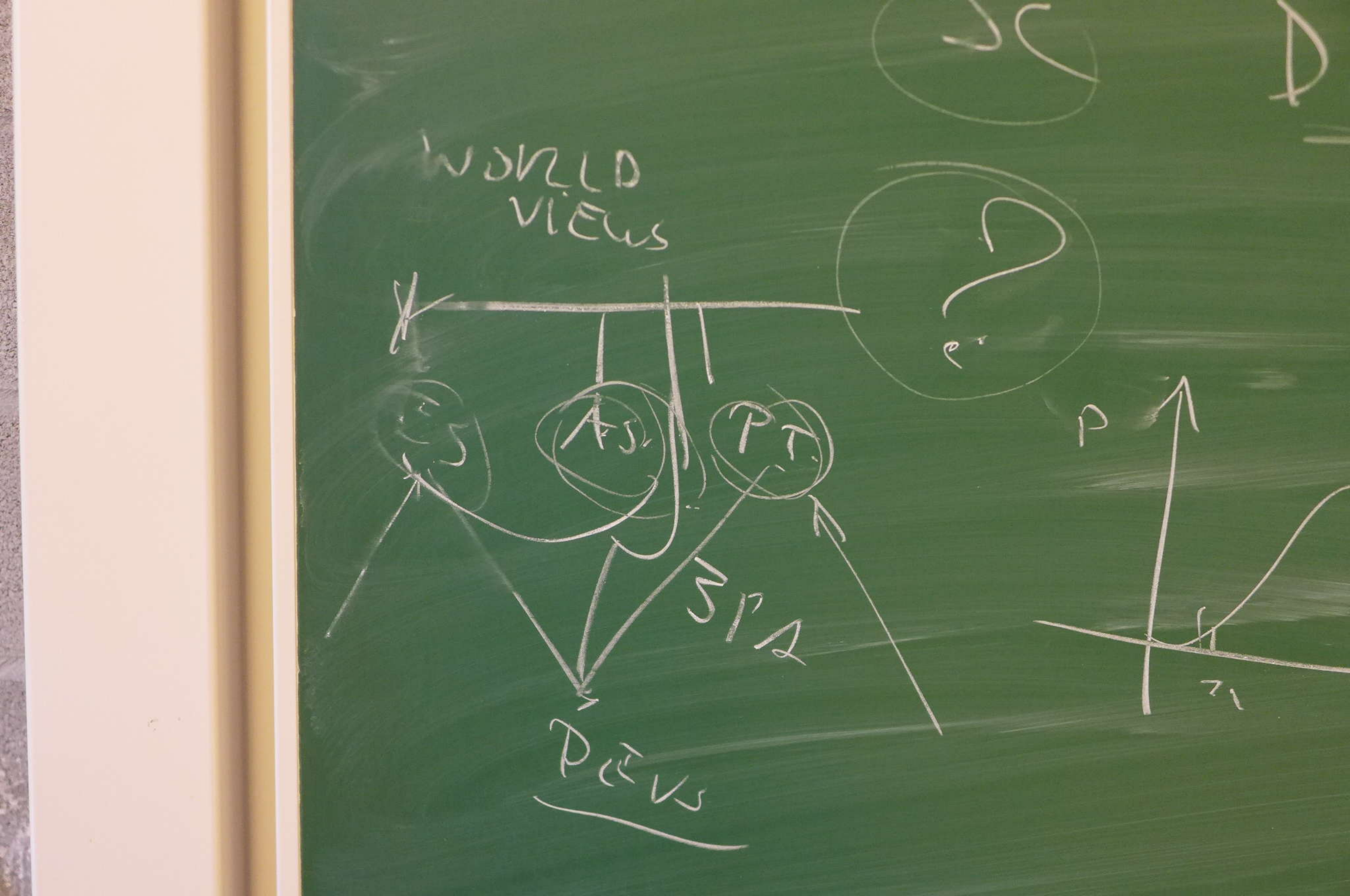

v1
v2


ARR
ARR
ARR
ARR
END


T
100°C
t
BOIL
t
I
II


ARR
IAT
t
TRACE-DRIVEN
I
ARR
SYS
ENV
ENV/ARR
II
ES, Model
SYS
AUTO-GENERATIVE
EL
Arr
(to)
CURRENT
EVEN


PRIORITY
DEP > ARR
ABSTRACT?
EL
ARR
DEP
200
END
1000
ARR
1100
DEP
1000
ARR
200
CURRENT
EVENT
ILLEGITIMATE



WORLD
VIEWS
PT.
P

DISCRETE-EVENT

PN

SC

?

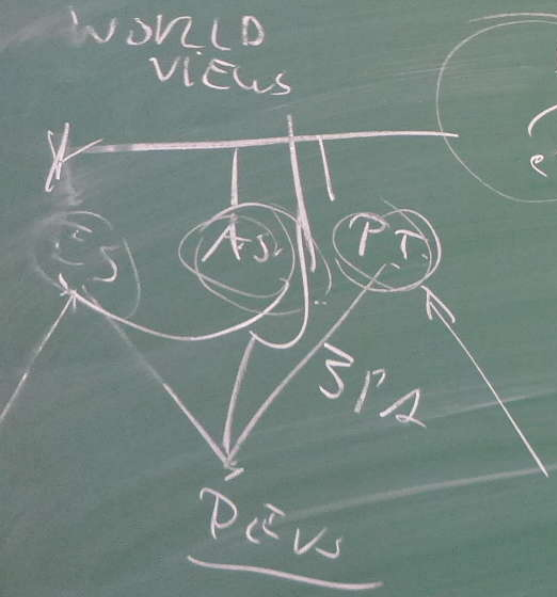
NON-DET → ANALYSIS

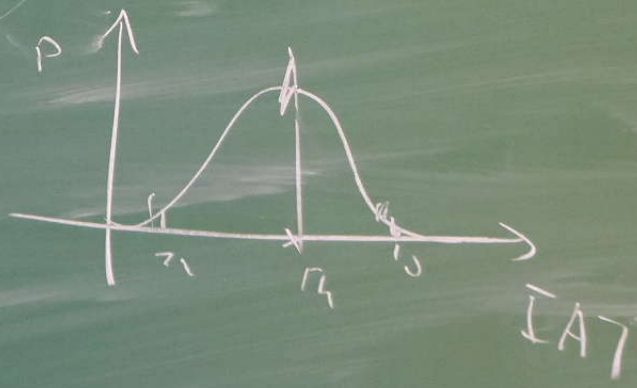
DET. → SIM / CODE SYNTH

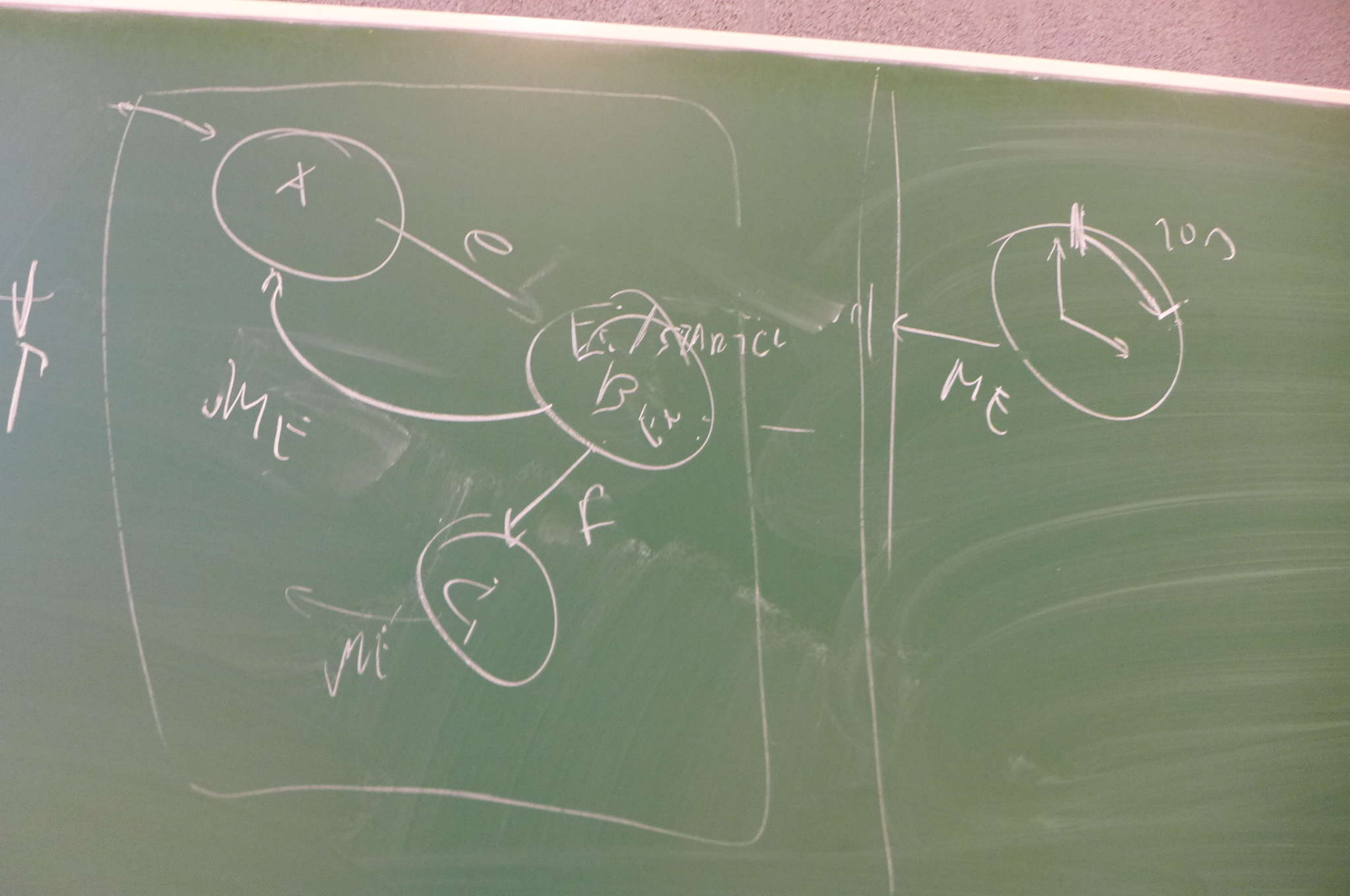
PERFORMANCE ANALYSIS

QN

LT






A
e
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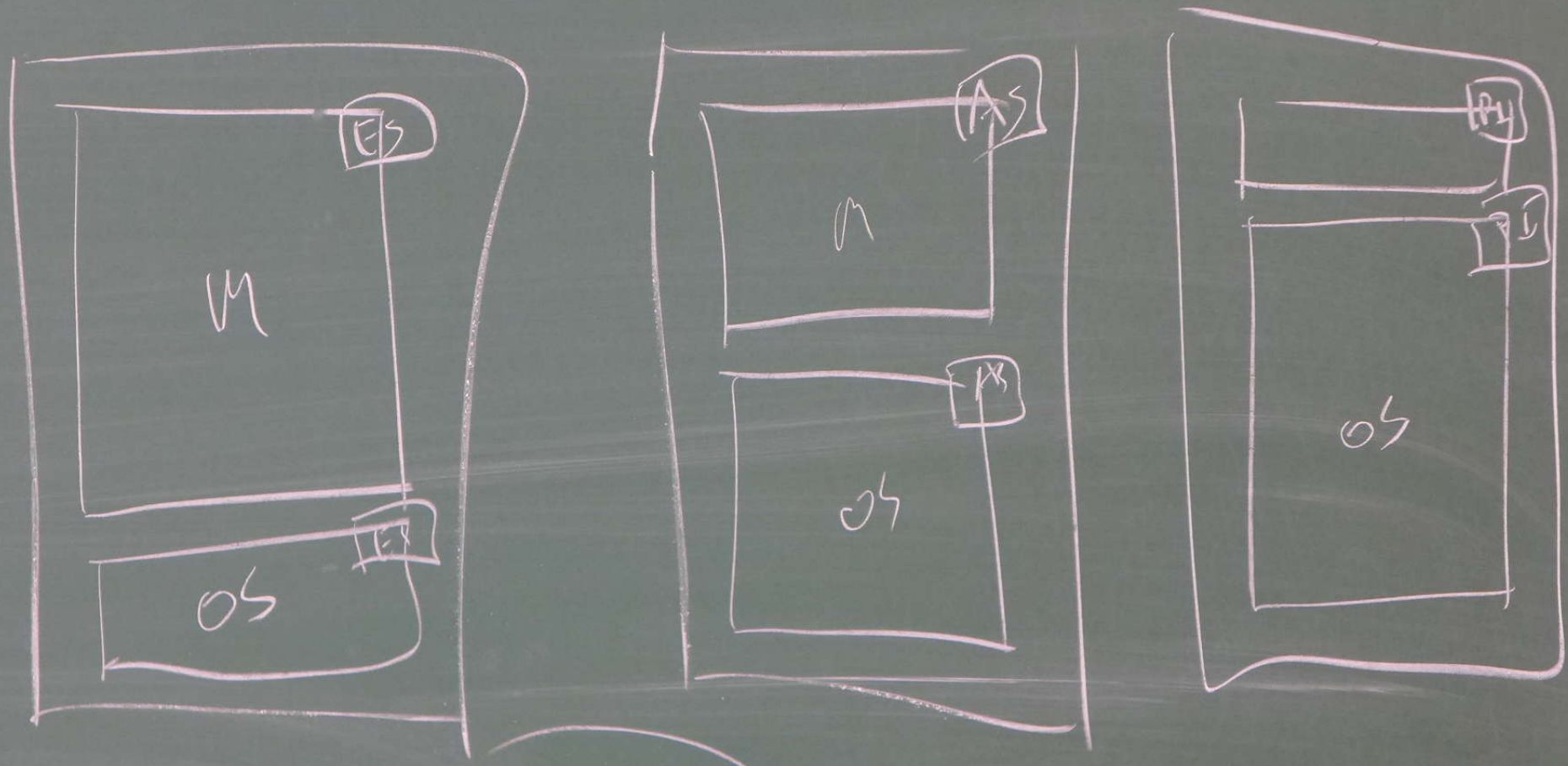
M
OS
M
OS
OS

CASHIER
CASHIER

- SD, CD, REGEXPR
- CBD (AIG, DT, CT)
- PN
- SC
- ES / AS / PI → DEVS

Q

BASIC

① MAPPED ONTO FSD

② OTHER

③ COMBINATIONS

SPATIAL

INDIVIDUALS

SYSTEMS THEORY

⊥ × REAL-TIME $t_a \geq 0$

× SYSTEMS THEORY