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Success is the sum of small efforts,
repeated day in and day out.

Theory of Computation

Regular Exp:

I) $\phi . R = R . \phi = \phi$

II) $R . \varepsilon = \varepsilon . R = R$

III) $\Sigma^* + R = \Sigma^*$

IV) $a^* = \varepsilon + a^+ = (a^*)^* = (a^*)^+ = (a^+)^* = (a^*)^2$

Imp: V) $(a+b)^* = (a^* b^*)^* = (a^* b^*)^+ = (b^* a^*)^* = (a^* b^*)^+$

$= b^* (a b^*)^* = a^* (b a^*)^* = (a^* b)^* a^* = (b^* a)^* b^*$

$\Sigma = \{a, b\}$

Language	Reg Exp	Min DFA	Min NFA	RG
① starts with 'a'	$= a(a+b)^*$ $= (ab^*)^+$	3 states	2 states	$S \to aA$ $A \to aA \mid bA \mid \varepsilon$
② Empty Set	ϕ	1 state	1 state	Empty Grammar
③ Ends with 'a'	$= (a+b)^*a$ $= (b^*a)^+$	2 states	2 states	$S \to Aa$ $A \to Aa \mid Ab \mid \varepsilon$

Language	Reg Exp	Min DFA	Min NFA	RG
④	$\Sigma^* aaa$	$\|aaa\|+1$ = 4	$\|aaa\|+1$ = 4 states	
⑤	$aaa\,\Sigma^*$	$\|aaa\|+2$ = 5 states	$\|aaa\|+1$ = 4 states	
⑥	$\Sigma^* aaa \Sigma^*$	= 4 states	= 4 states	

Language	Reg Exp	Min DFA	Min NFA	RG

Language	Reg Exp	Min DFA	Min NFA	RG

Language	Reg Exp	Min DFA	Min NFA	RG
⑦ $\lvert w\rvert = 2$ (K)	$\Sigma^2 = (a+b)^2$	4 states (K+2)	3 states (K+1)	
⑧ $\lvert w\rvert \leq 2$	$(\varepsilon+a+b)^2$	4 states	3 states	
⑨ $\lvert w\rvert \geq 2$	$(a+b)^2\Sigma^*$	3 states	3 states	
⑩ $n_a(w) = 2$	$b^*ab^*ab^*$	4	3	
⑪ $n_a(w) \leq 2$	$b^*(\varepsilon+a)b^*(\varepsilon+a)b^*$	4	3	
⑫ $n_a(w) \geq 2$	$\Sigma^*a\Sigma^*a\Sigma^*$	3	3	

Language	Reg Exp	Min DFA	Min NFA	RG
(13) 3rd Symbol from left is 'a' (begin)	$(a+b)^2 a \Sigma^*$	= 3+2 = 5 states	= 4 states	
(14) 3rd Symbol from right is 'a' (end)	$\Sigma^* a \Sigma^2$	$= 2^3 = 8$ states	= 4 states	

(15) $L = \{ w \mid w \in \{a,b\}^*, n_a(w) \text{ is div by } 3, n_b(w) \text{ is div by } 5 \}$

$= 3 \times 5$

$= 15$ states

(16) $|w|$ is div by n $\Longrightarrow$ n states

(17) $n_0(w)$ " n $\Longrightarrow$ n states

***(18) $\{w \mid w \in \{0,1\}^*,$ Der(w) is divisible by $\underline{1024}\}$

$\Downarrow$

2^{10} $\Longleftarrow$ $10+1$

$= 11$ states

(19) $\{ w \mid w \in \{0,1\}^*, \text{Dec}(w) \text{ is div by } 7 \}$

↓ Prime or odd

7 states

Finite Language

Regular but not finite

DCFL but not Regular

CFL but not DCFL

Not CFL

① $\{a^m b^n\} \Rightarrow a^* b^* \Rightarrow$ Regular, not finite

② $\{a^n b^n\} \Rightarrow$ DCFL but not reg

③ $\{a^m b^n \mid m=n \text{ or } m=2n\} \Rightarrow$ CFL but not DCFL

④ $\{a^n b^n c^n\} \Rightarrow$ not CFL

⑤ $\{ww \mid w \in \{a,b\}^*\}$ ⟹ Not CFL

⑥ $\{w\#w \mid \quad ''\quad\}$

Imp ⑦ $\{ww^R \mid \quad ''\quad\}$ ⟹ CFL but not DCFL

⑧ $\{w\#w^R \mid \quad ''\quad\}$ ⟹ DCFL but not reg

$= (a+b)^*$

(9) $\{ w x w^R \mid w, x \in \{a,b\}^* \}$ $\Rightarrow$ Regular, not fin

(10) $\{ x w w^R \mid \quad " \quad \}$

(11) $\{ w w^R x \mid \quad " \quad \}$

(12) $\{ w x w^R \mid w, x \in \{a,b\}^* \}$ $\Rightarrow$ Reg

(13) $\{ x w w^R \mid \quad " \quad \}$

(14) $\{ w w^R x \mid \quad " \quad \}$

CFL but not DCFL

(15) $\overline{\{a^n b^n\}}$ → DCFL

(16) $\{a^n b^n\}^*$ → DCFL

(17) $\overline{\{ww^R \mid w \in \{a,b\}^*\}}$ → CFL but not DCFL

(18) $\overline{\{ww \mid w \in \{a,b\}^*\}}$ → CFL but not DCFL

(19) $\overline{\{a^n b^n c^n\}}$ → CFL but not DCFL

Great things never come from comfort zones.

Closure properties:

SIALL

For Regulars:

↳ Not closed: Subset, Inf(union, ∩, −, ·, ⊆, f)

CPIFs

For DCFLs:

↳ closed: Complement, Prefix, h^{-1}, Finite subset

For CFLs:

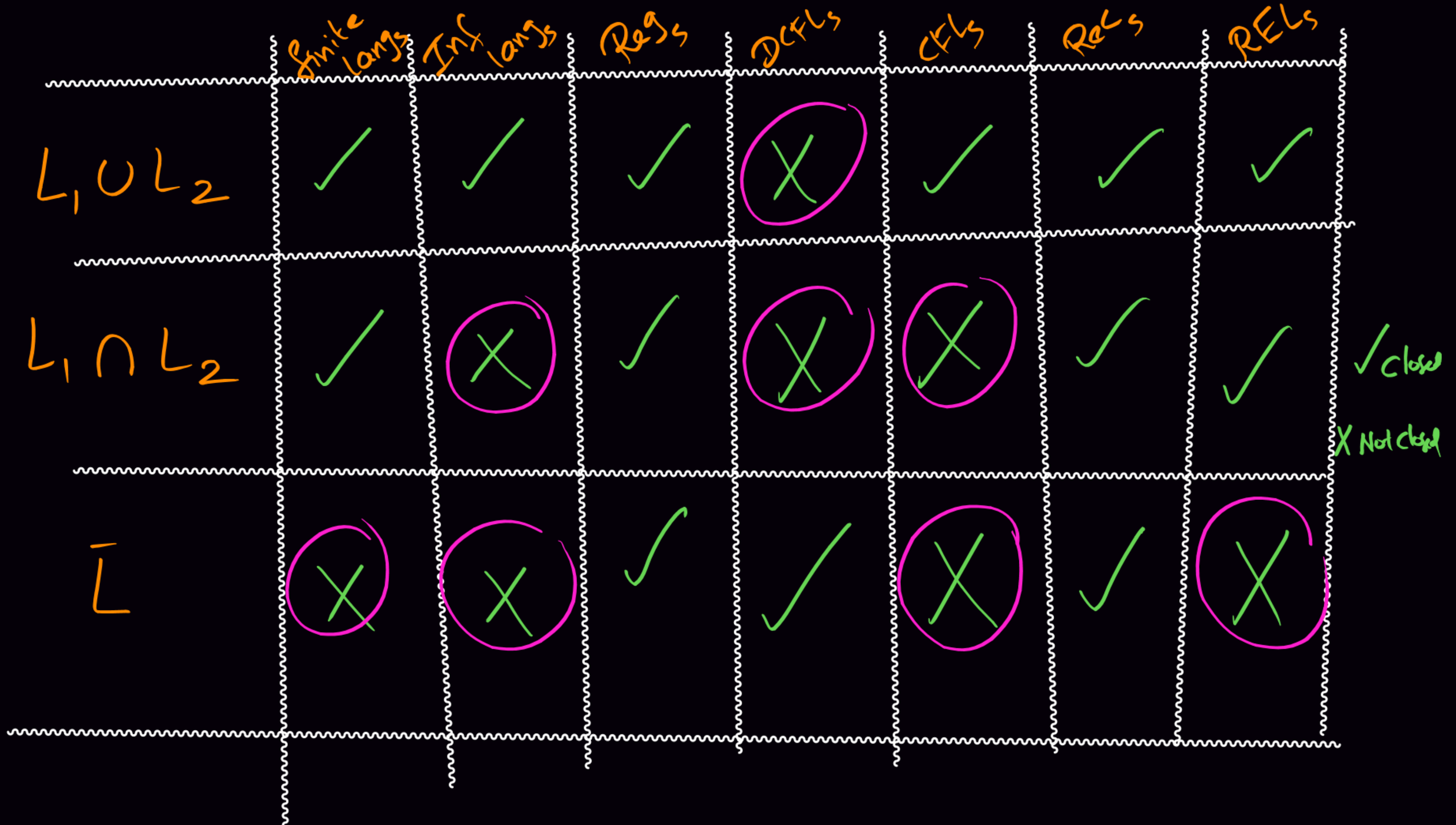
↳ Not closed: ∩, ∩, Diff, Subset, Quotient, Finite ∩, Fin − Inf(....)

For Recs (Decidables):

↳ Not closed: Substitution, Homomorphism, ⊆, Inf....

For RELs
(SDs)

↳ Not closed: Complement, Difference, Subset,
Finite Diff, Inf(...)


Finite langs
Inf langs
Regs
DCFLs
CFLs
RaLs
RELs
$L_1 \cup L_2$
$L_1 \cap L_2$
$\bar{L}$
✓ Closed
X Not Closed

① a^*

i) $S \to aS \mid \varepsilon$

ii) $S \to Sa \mid \varepsilon$

iii) $S \to aS \mid Sa \mid \varepsilon$

iv) $S \to SS \mid a \mid \varepsilon$

⋮

② $(a+b)^*$

$$S \rightarrow aS \mid bS \mid \varepsilon$$

OR

$$S \rightarrow Sa \mid Sb \mid \varepsilon$$

③ $\{a^n b^n\}$

$$A \rightarrow aAb \mid \varepsilon$$

④ $\{ww^R \mid w \in \{a,b\}^*\}$

$$S \rightarrow aSa \mid bSb \mid \varepsilon$$

⑤ $\{a^m b^n \mid m \geq n\}$

$S \rightarrow AB$

$A \rightarrow aAb \mid \varepsilon$

$B \rightarrow aBb \mid \varepsilon$

⑥ $\{a^m b^n \mid m \leq n\}$

$S \rightarrow AB$

$A \rightarrow aAb \mid \varepsilon$

$B \rightarrow bB \mid \varepsilon$

⑦ $S \rightarrow aS \mid Sb \mid \varepsilon$

$L = a^* b^*$

(L) Recursive Lang

HTM exist

Decidable lang

L is REL and $\bar{L}$ is REL

L has TM & $\bar{L}$ has TM

L enumerates in effective order (lexicographical)

(L) REL

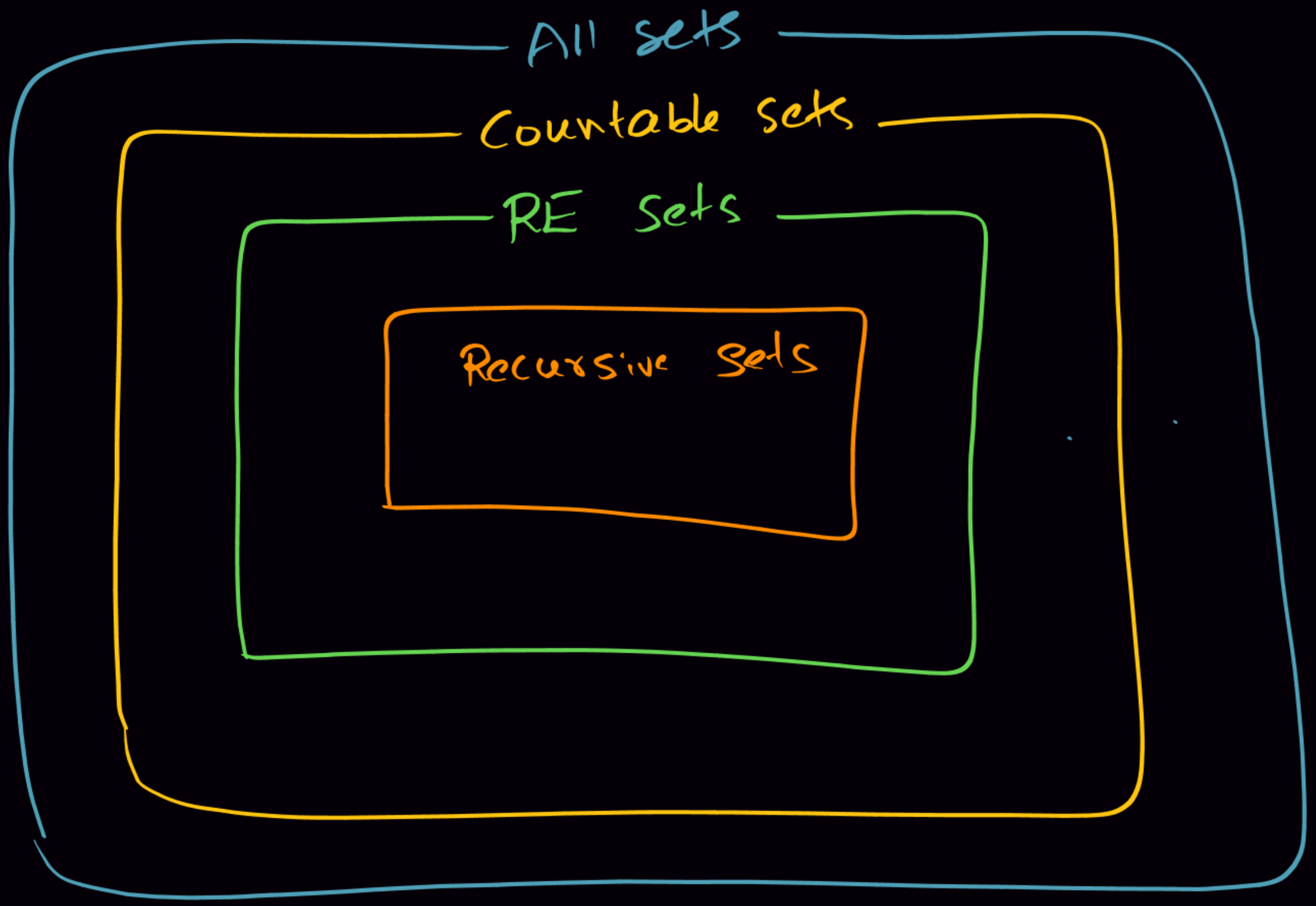
TM exist

Semidecidable lang

L is either Recursive or SD UD (RE but not Rec)

L enumerated by TM

Turing Recognizable language


All sets
Countable sets
RE sets
Recursive sets

	Regs	DCFLs	CFLs	Recs	REls
H M	D	D	D	D	
E F	D	D	D		
T E	D	D			
D S	D				

I) $\{TM \mid TM \text{ accepts } \varepsilon\}$ → Undecidable & semidecidable

Membership

II) $\{Tm \mid Tm \text{ accepts Some string}\}$ → Undecidable & semidecidable

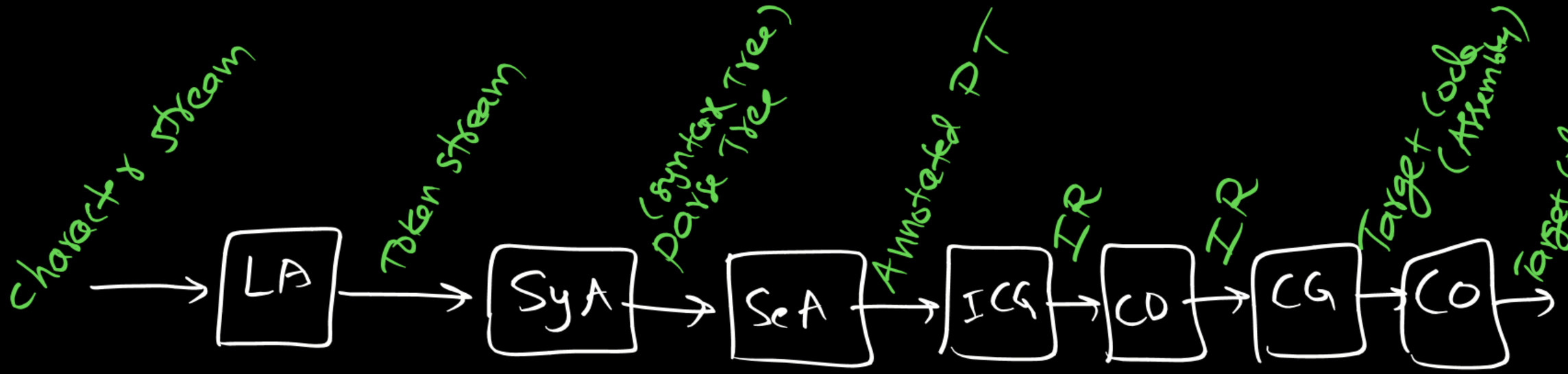
Non-emptiness

III) $\{Tm \mid Tm \text{ accepts only } \varepsilon\}$ → Undecidable & not RE (not semidecidable)

$L(Tm) = \{\varepsilon\}$

Compiler Design

Compiler phases



Lexical Analysis

- Tokens:
  - Identifiers (variable names, function names)
  - Operators
  - constants
  - Keywords
  - Punctuations

```
f ( )
{
    int  x = 10;
    x++;
    **x;
}
```

++ → 1 token

** → 2 tokens

= 17 tokens

Lexical Analysis

- longest Prefix match rule
- TOKens
- Lexical errors

int 1xy;

int x=029;
↳ not octal digit

/* . . . . .

Syntax Analysis

- Syntax errors
- Amb & Unamb CFGs
- First and Follow set
- LL(1) CFG ?
- LL(1) Table
- LR CFGs ?
- Operator precedence

Amb CFG: Some string, >1 derivation.

Unamb CFG: Every string, 1 derivation.

I) $S \rightarrow Sa \mid bS \mid c$

Amb CFG

II) $S \rightarrow AB \mid ab$

$A \rightarrow a$

$B \rightarrow b$

Amb CFG

$$A \rightarrow A\alpha_1 \mid A\alpha_2 \mid \beta_1 \mid \beta_2 \mid \beta_3$$

Left Recursion Elimination

$$A \rightarrow \beta_1 X \mid \beta_2 X \mid \beta_3 X$$

$$X \rightarrow \alpha_1 X \mid \alpha_2 X \mid \epsilon$$

$$A \rightarrow ab \mid ac \mid ad \mid ef$$

Left factoring
(eliminate common prefixes)

$$A \rightarrow aX \mid ef$$
$$X \rightarrow b \mid c \mid d$$

Left factored CFG

IMP:

How to check LL(1) CFG ?

Rule 1:

$$A \rightarrow \alpha_1 \mid \alpha_2$$

$\Downarrow$

If $First(\alpha_1) \cap First(\alpha_2) \neq \phi$

then "not LL(1)"

Rule 2:

$$A \rightarrow \alpha \mid \varepsilon$$

$\Downarrow$

If $Fi(\alpha) \cap Fo(A) \neq \phi$

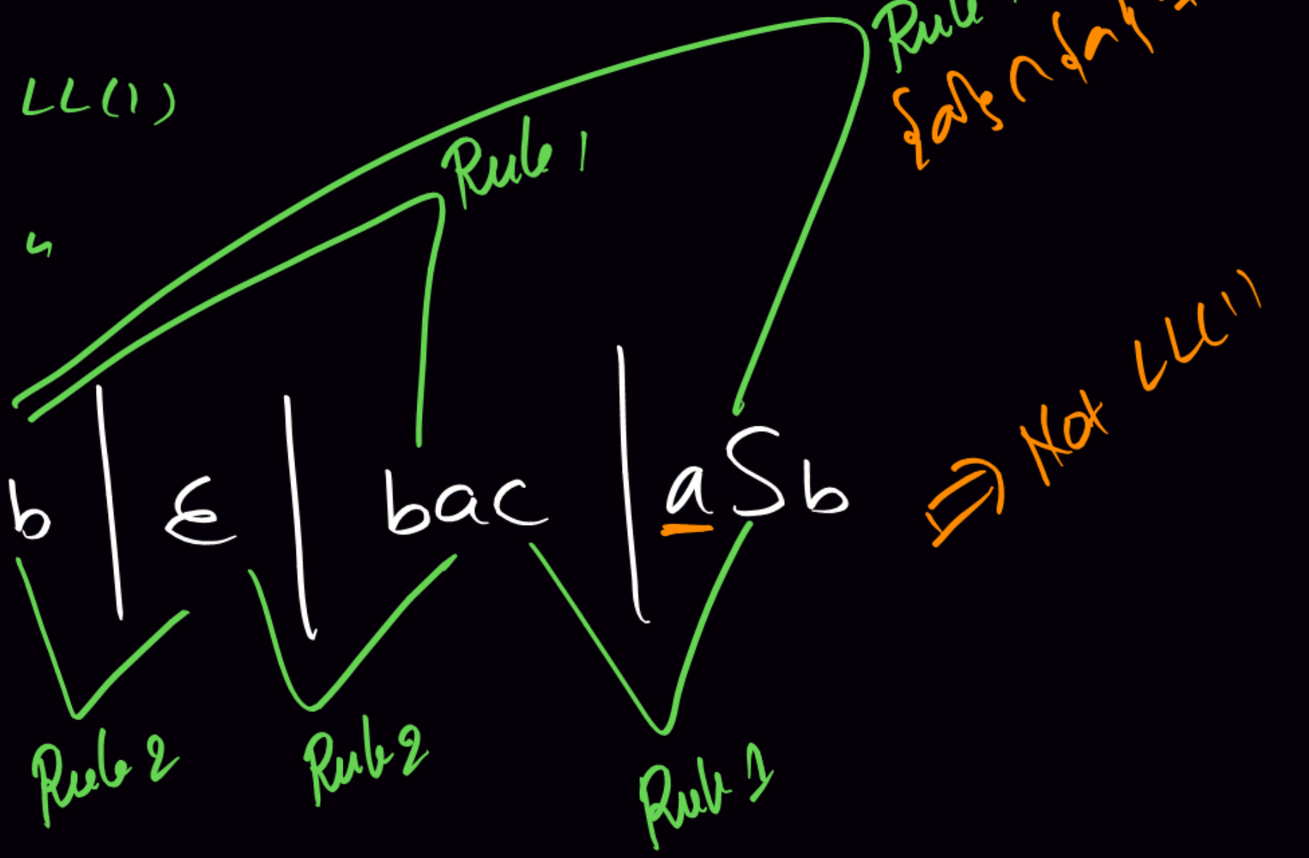
then not LL(1)

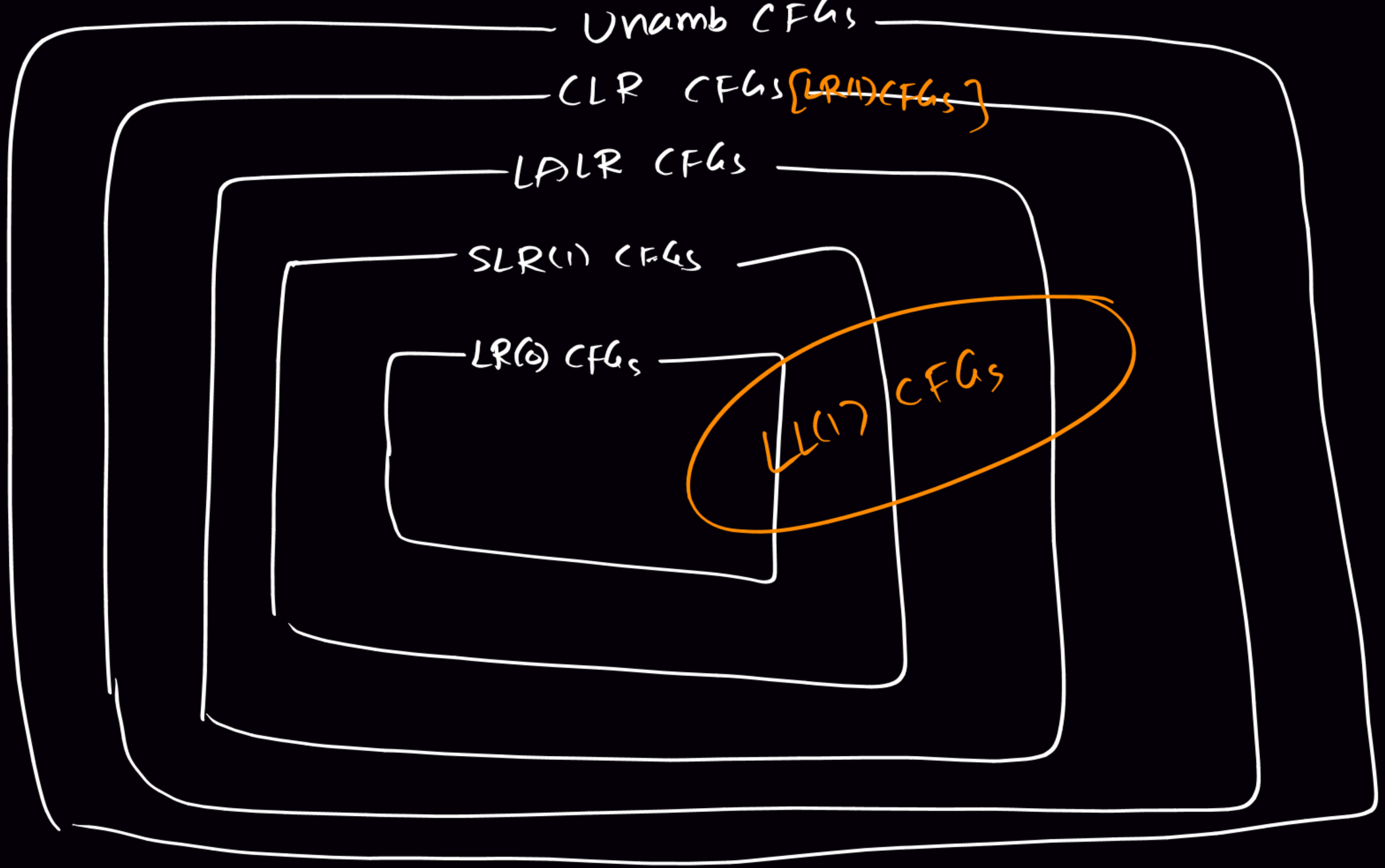
1) $S \rightarrow Sa S \mid \varepsilon$ ⇒ Not LL(1)

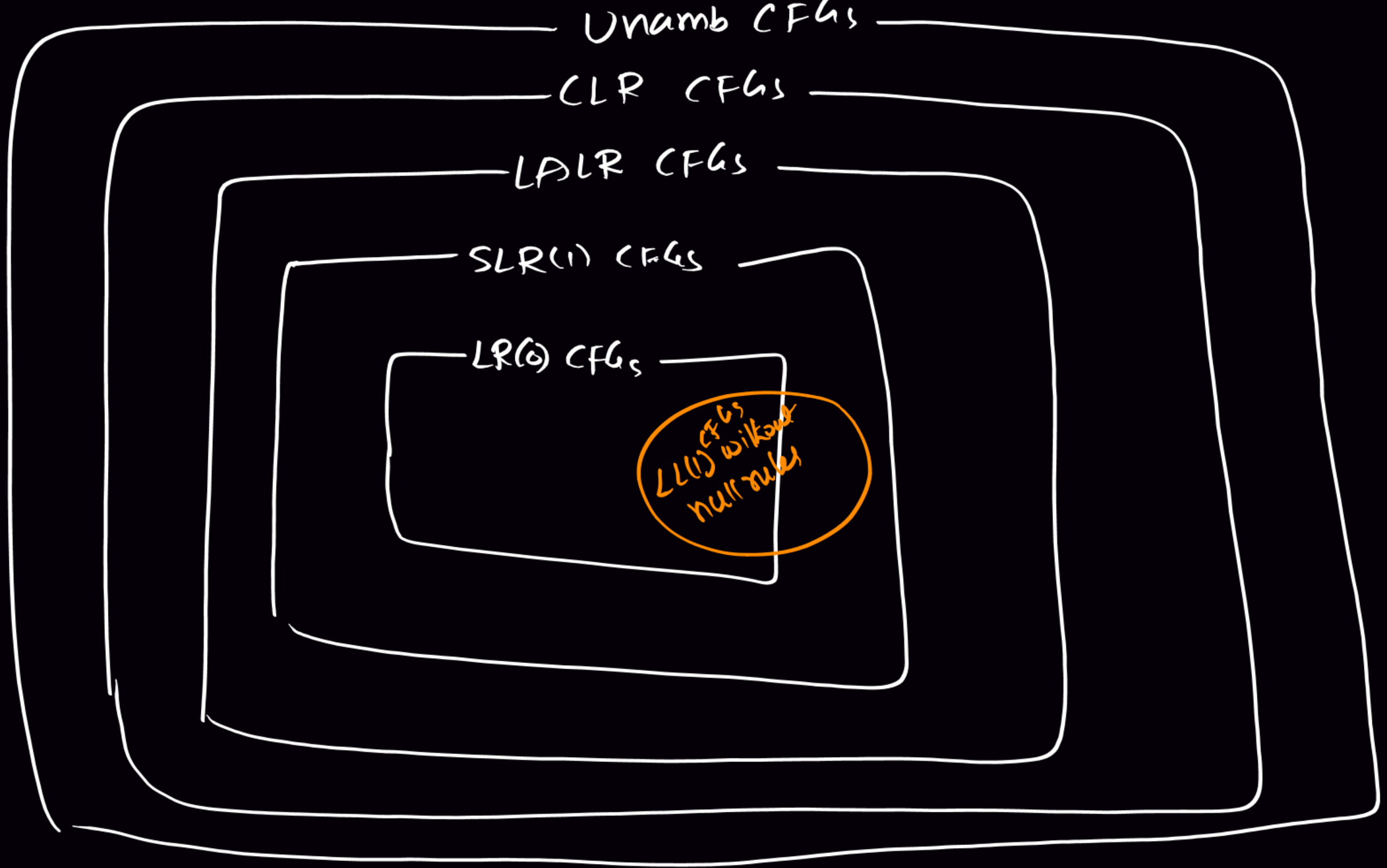
I) Amb CFG never be LL(1)

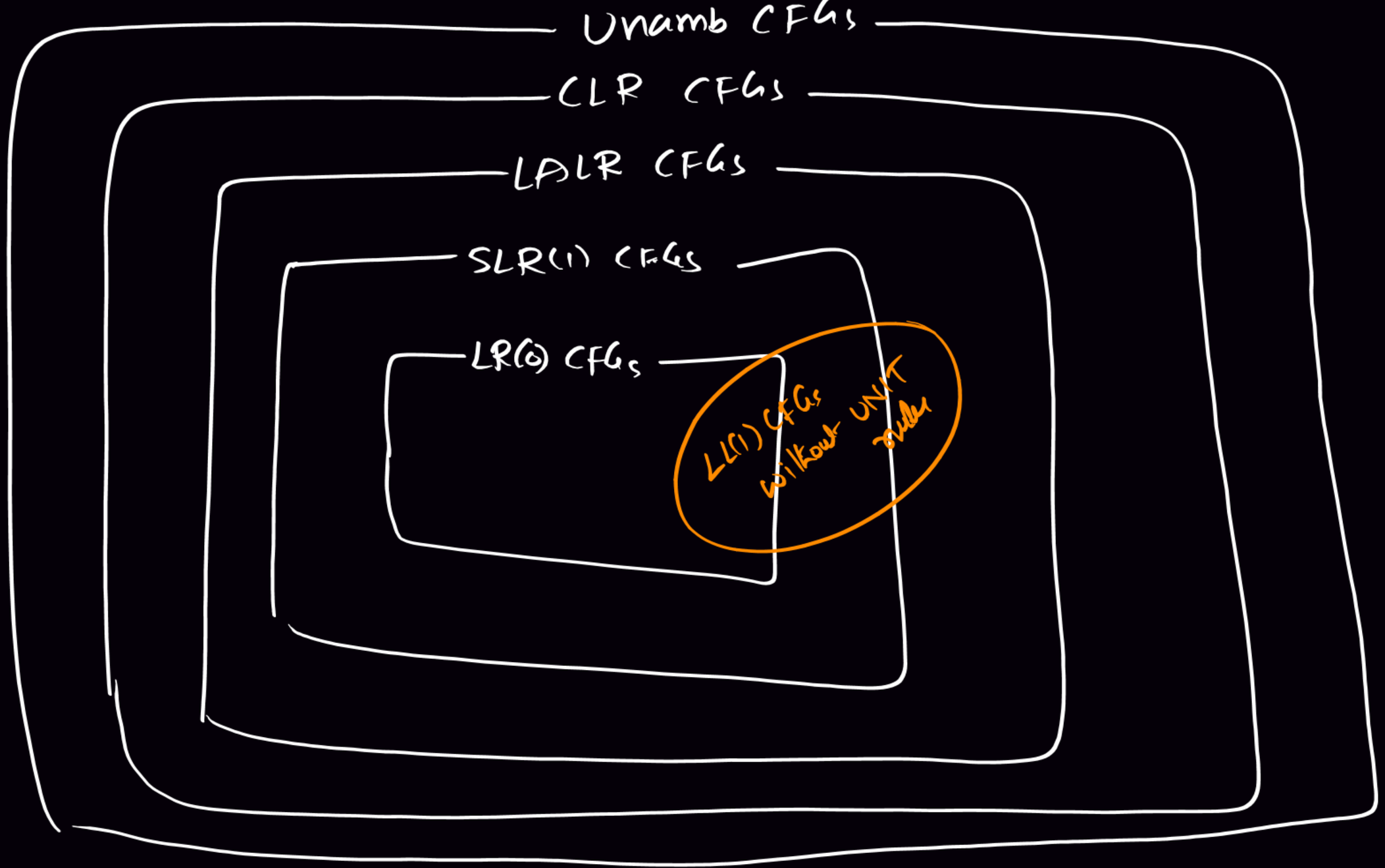
II) Left Rec CFG " "

2) $S \rightarrow ab \mid \varepsilon \mid bac \mid aSb$ ⇒ Not LL(1)




Unamb CFGs
CLR CFGs [LR(1) CFGs]
LALR CFGs
SLR(1) CFGs
LR(0) CFGs
LL(1) CFGs


Unamb CFGs
CLR CFGs
LALR CFGs
SLR(1) CFGs
LR(0) CFGs
LL(1) CFGs without null rules

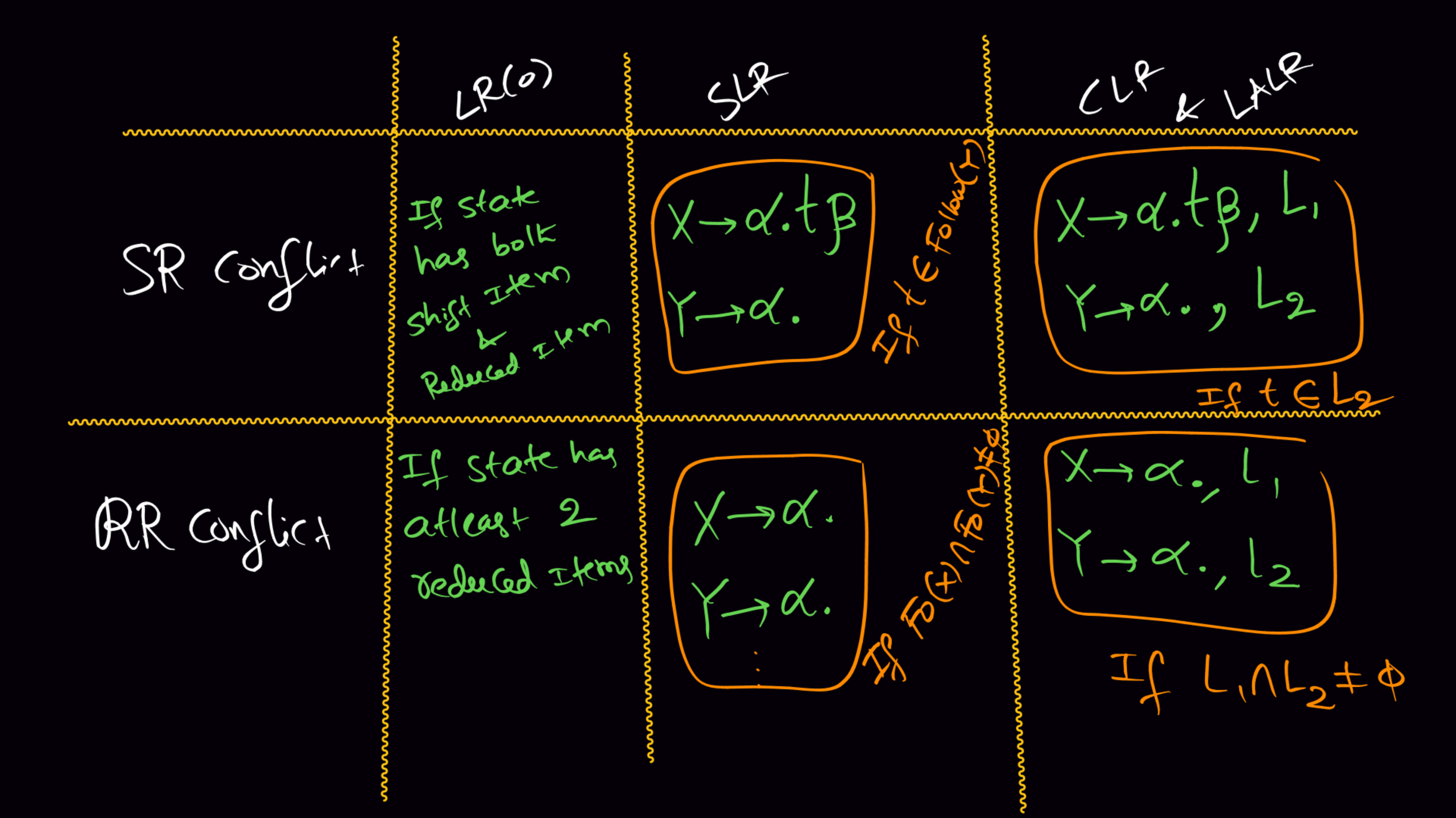

Unamb CFGs
CLR CFGs
LALR CFGs
SLR(1) CFGs
LR(0) CFGs
LL(1) CFGs without UNIT rules

Every LL(1) CFG is LR(1) CFG.

Set of LR(1) languages

=

Set of DCFLs


LR(0)
SLR
CLR & LALR
SR conflict
If state has both shift item & Reduced item
$X \to \alpha . t \beta$
$Y \to \alpha .$
If $t \in Follow(Y)$
$X \to \alpha . t \beta, L_1$
$Y \to \alpha ., L_2$
If $t \in L_2$
RR conflict
If state has atleast 2 reduced items
$X \to \alpha .$
$Y \to \alpha .$
If $Follow(X) \cap Follow(Y) \neq \phi$
$X \to \alpha ., L_1$
$Y \to \alpha ., L_2$
If $L_1 \cap L_2 \neq \phi$

I) If State (set of Items) has no reduced Item, it never produces any conflict.

II) If state has only 1 Item, it never produces any conflict.

I) LR(0) parser < SLR < LALR < CLR (LR(1))

Less powerful!
Easy to Implement

More powerful!

II) LR(0) CFG ⟹ SLR CFG ⟹ LALR CFG ⟹ CLR CFG

CLR CFG ⇓ Unamb CFG

*** III) If CFG is Ambiguous ⟹ not LL(1)
not LR(0)
not SLR
not LALR
not CLR

IV) no. of states:

$$n(LR(0)) = n(SLR) = n(LALR) \leq n(CLR)$$

V) no. of shift entries:

$$n(LR(0)) = n(SLR) = n(LALR) \leq n(CLR)$$

VI) no. of state entries:

$$n(LR(0)) = n(SLR) = n(LALR) \leq n(CLR)$$

VII) no. of Reduced entries:

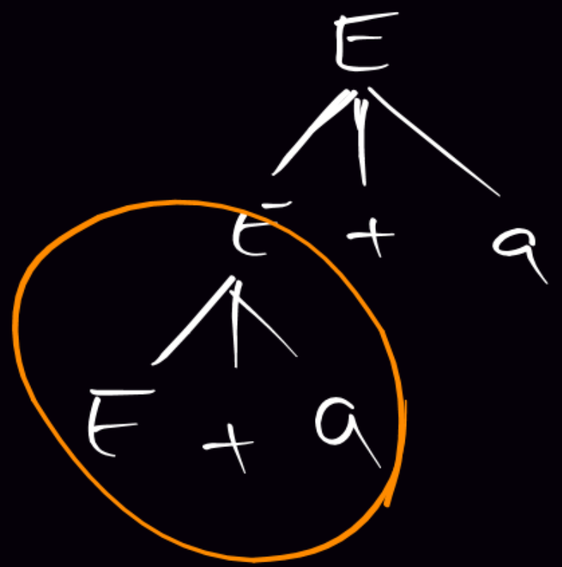
$$n(LR(0)) \geq n(SLR) \geq n(LALR)$$

Operator precedence:

I) $E \rightarrow E + a \mid a$

+ is Left Associative

$a + a + a$



II) $E \rightarrow a + E \mid a$

$\Downarrow$

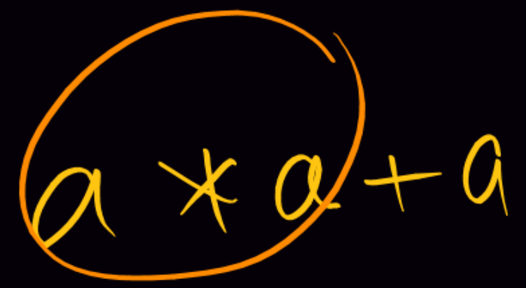
+ is Right Associative

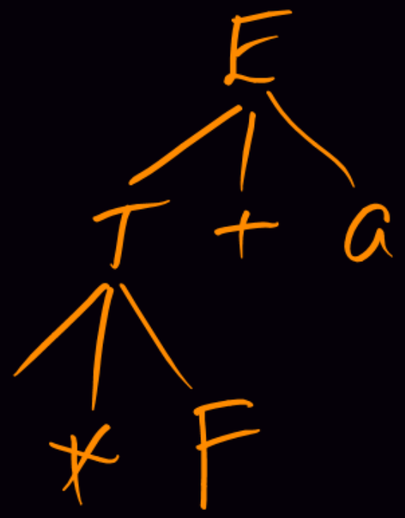
III)

$E \rightarrow T + a$

$T \rightarrow a * F$

$F \rightarrow a$



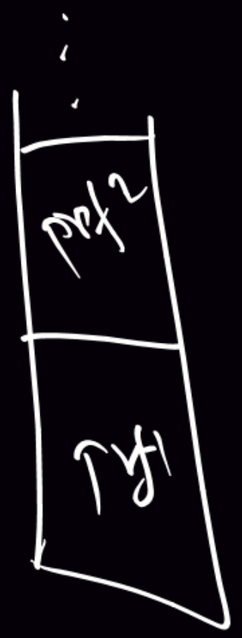


* has highest precedence

Handle: production appears only at the top of stack

Viable prefix:

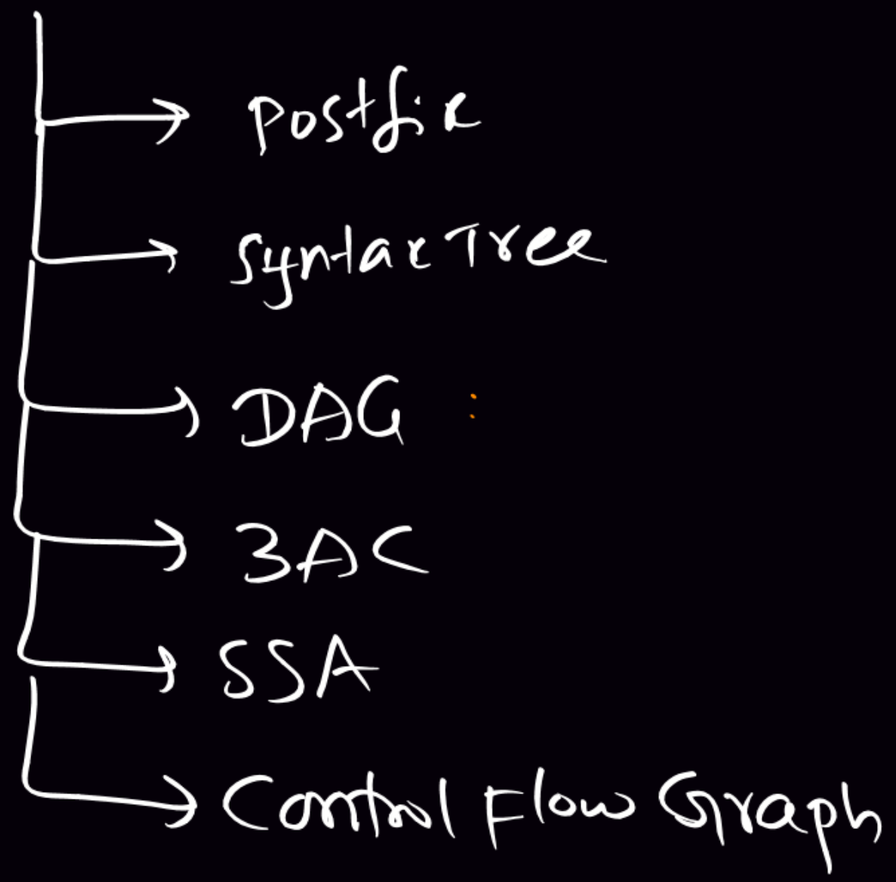
↳ stack contains set of viable prefixes

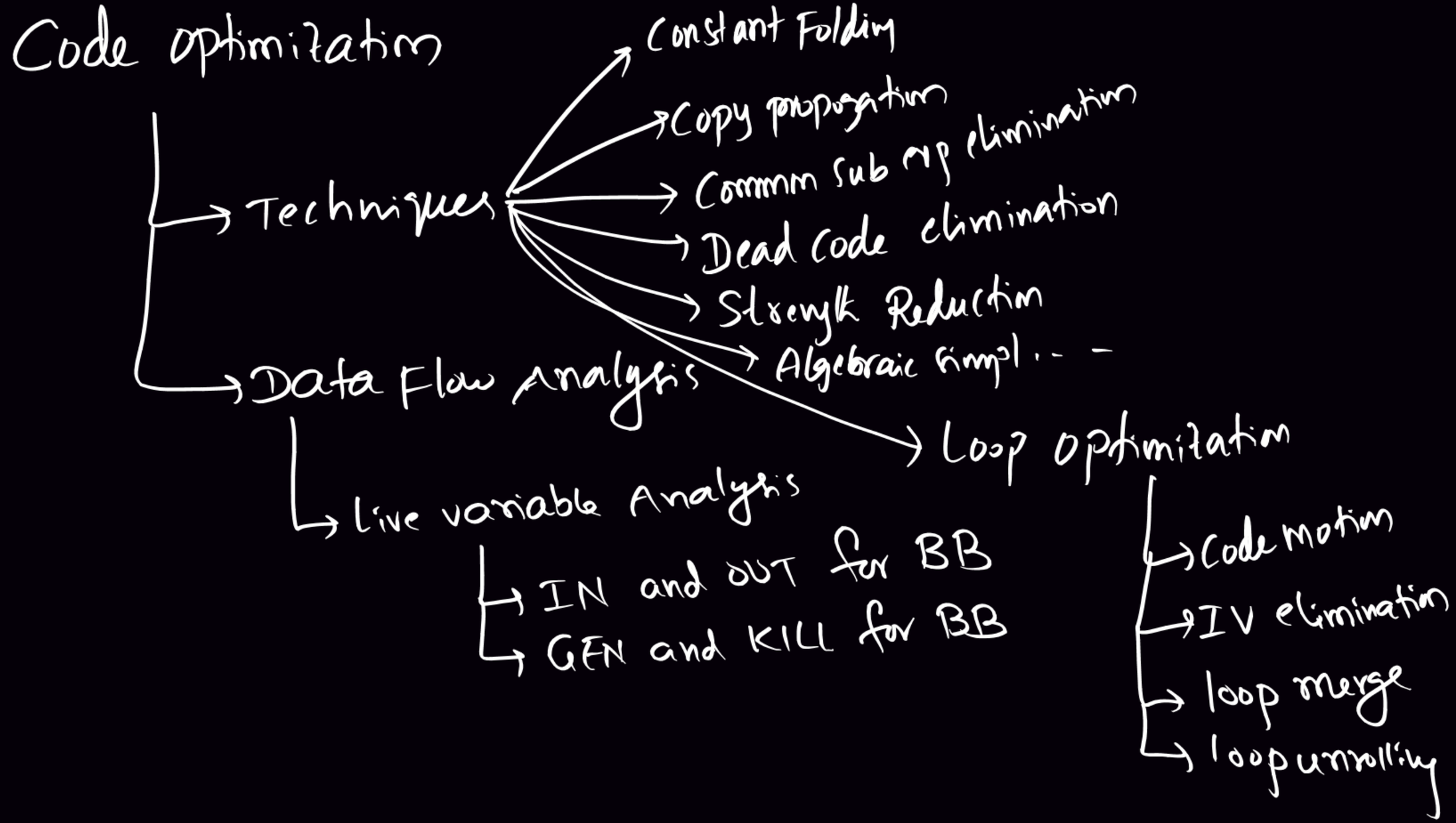


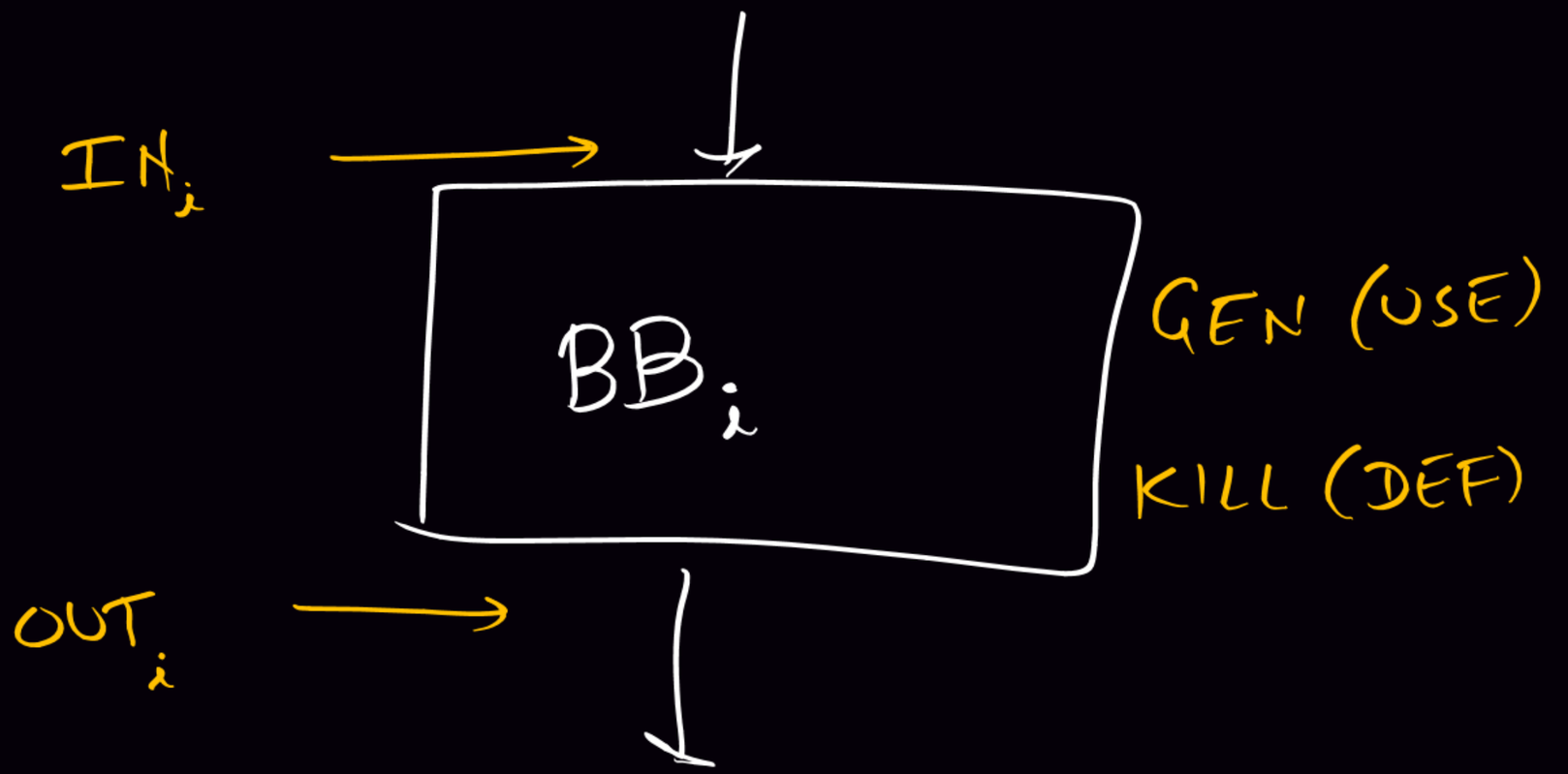
SDTs

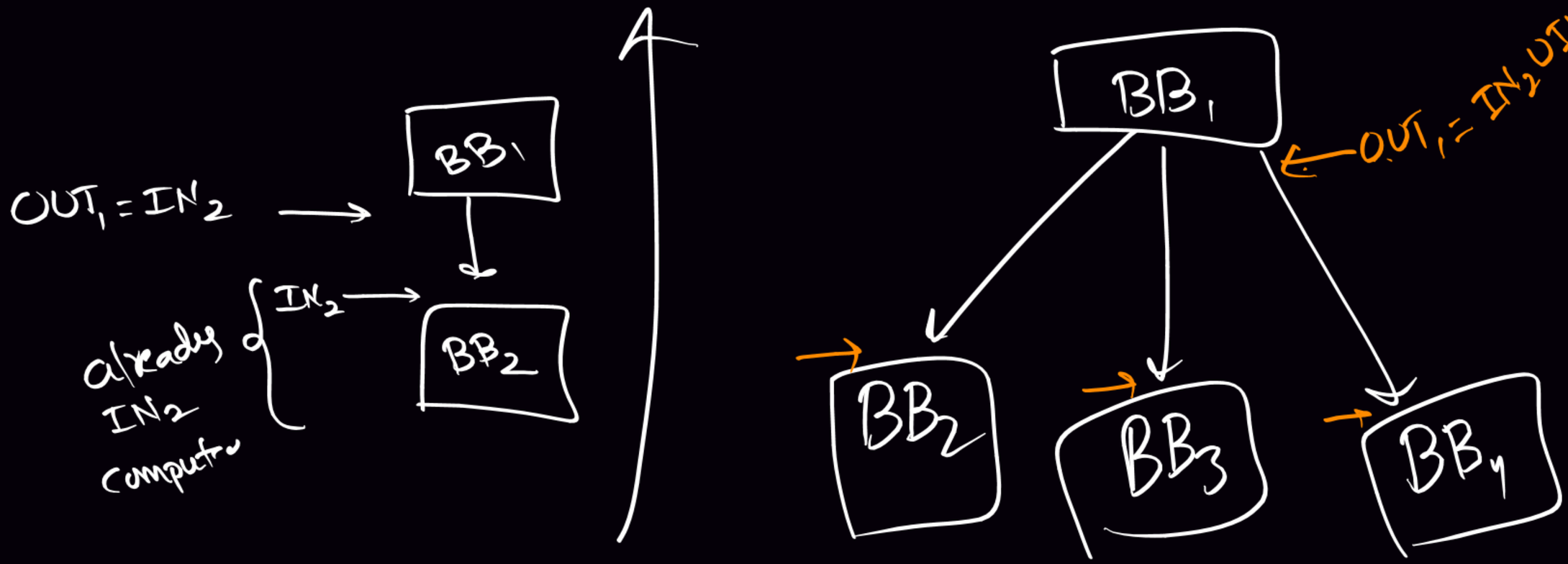
- Attributes
  - Inherited : Depends on parent/sibling
  - Synthesized : Depends on children
- Definitions (Types of SDTs)
  - L-attributed grammar (Depends on parent/left sibling/children)
  - S-attributed grammar (Depends on children) (Translation is at end)
- Evaluations
  - Attributed Grammar → Use L-attributed evaluation
  - Actions → TDP / BUP → L-attributed eval / anything...

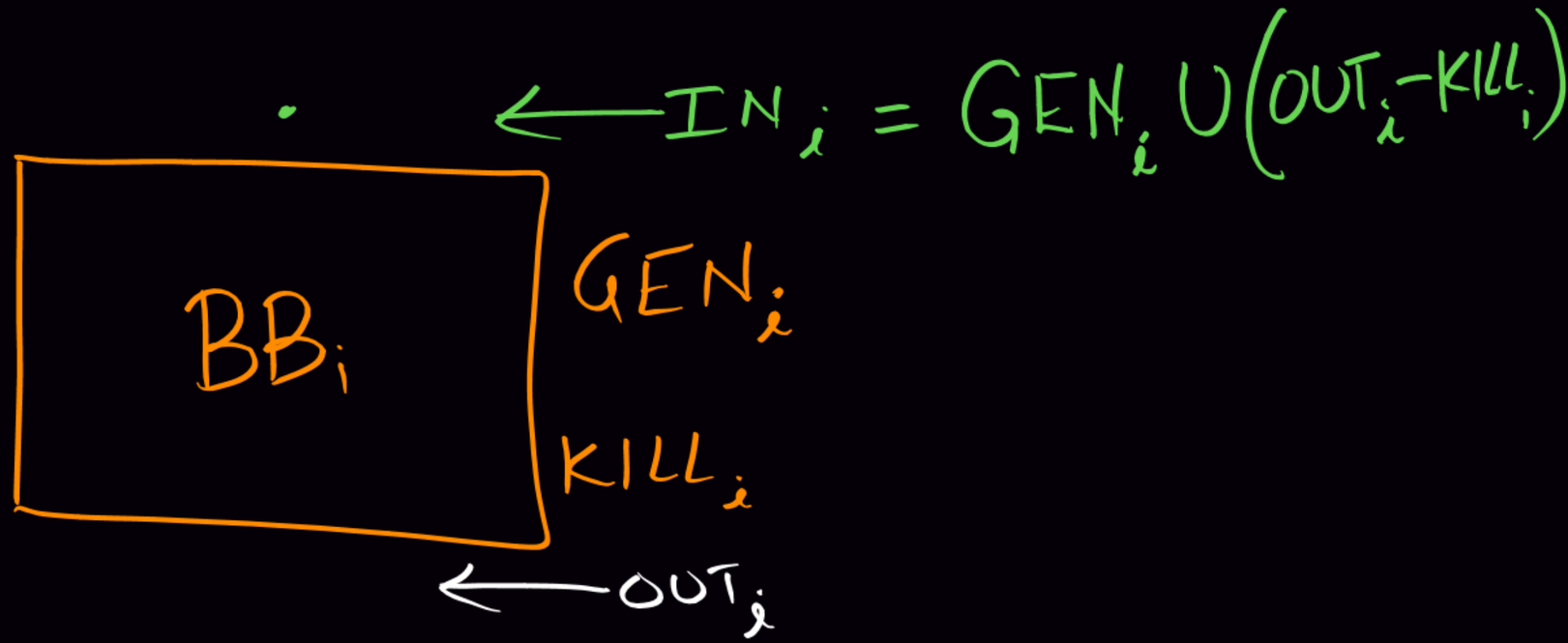
IR :




Code optimization
Techniques
Constant Folding
Copy propogation
Common sub exp elimination
Dead code elimination
Strength Reduction
Algebraic Simpl...
Data Flow Analysis
Live variable Analysis
IN and OUT for BB
GEN and KILL for BB
Loop optimization
Code motion
IV elimination
loop merge
loop unrolling


IN_i
BB_i
GEN (USE)
KILL (DEF)
OUT_i

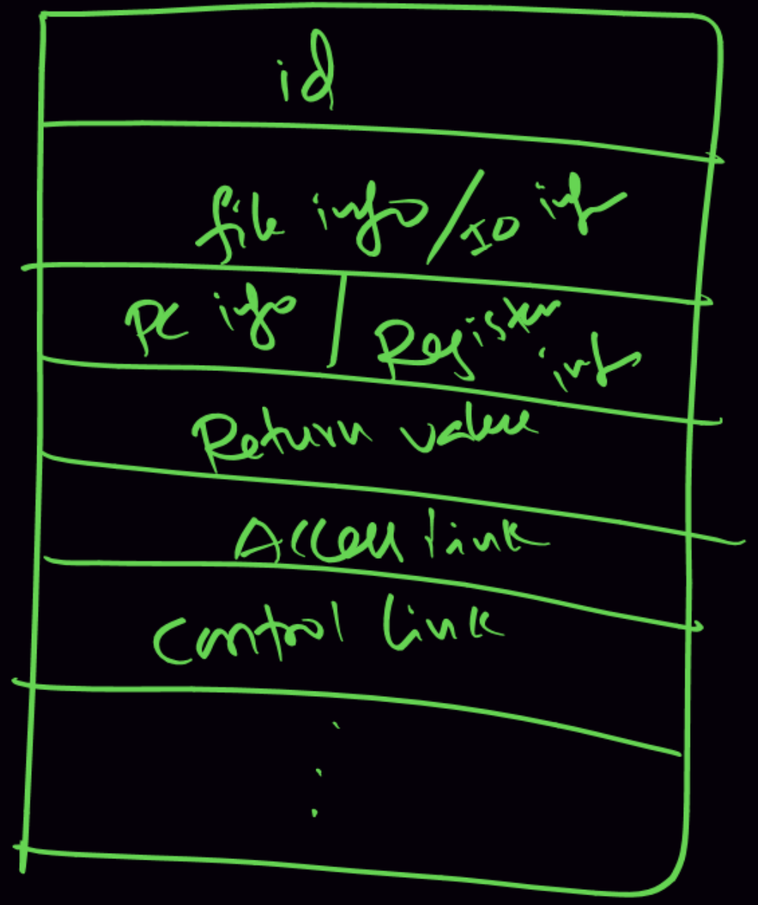

$OUT_1 = IN_2$
BB_1
already IN_2 computed
IN_2
BB_2
BB_1
$OUT_1 := IN_2 \cup IN_3 \cup IN_4$
BB_2
BB_3
BB_4


$IN_i = GEN_i \cup (OUT_i - KILL_i)$
BB_i
GEN_i
$KILL_i$
OUT_i

RTE

- Storage
  - static
  - stack
  - Heap
- Parameter passing : call by value & call by ref
- Scope : Static scope, Dynamic Scope
  - Static scope (lexical) → Depends on syntax
  - Dynamic Scope → Depends on calling sequence of fun

AR (frame


id
file info/IO info
PC info
Register info
Return value
Access link
Control link

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Mallesham Devsane


Satish Yadav


Vijay Kumar Agarwal

If you fell down yesterday, stand up today

ALL THE BEST

Thank You