Pre-lecture brain teaser

In the following languages, three are decidable and three are undecidable. Which are which?

- $A_{CFG} = \left\{ \langle G, w \rangle \;\middle|\; G \text{ is a } CFG \text{ that accepts string } w \right\}$.
- $E_{CFG} = \left\{ \langle G \rangle \;\middle|\; G \text{ is a } CFG \text{ and } L(G) = \emptyset \right\}$.
- $ALL_{CFG} = \left\{ \langle G \rangle \;\middle|\; G \text{ is a } CFG \text{ and } L(G) = \Sigma^* \right\}$.
- $A_{LBA} = \left\{ \langle M, w \rangle \;\middle|\; M \text{ is a } LBA \text{ that generates string } w \right\}$.
- $E_{LBA} = \left\{ \langle M \rangle \;\middle|\; M \text{ is a } LBA \text{ where } L(M) = \emptyset \right\}$.
- $ALL_{LBA} = \left\{ \langle M \rangle \;\middle|\; M \text{ is a } LBA \text{ where } L(M) = \Sigma^* \right\}$.

ECE-374-B: Lecture 25 - Midterm 3 Review

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April 26, 2022

University of Illinois at Urbana-Champaign

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A_{CFG} decidable?

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YES!

A_{CFG} decidable?

YES!

- $V = \{S\}$
- $T = \{0, 1\}$
- $P = \{S \rightarrow \epsilon \mid 0S0 \mid 1S1\}$
  (abbrev. for $S \rightarrow \epsilon, S \rightarrow 0S0, S \rightarrow 1S1$)

A_{CFG} decidable?

YES!

Lemma
A CFG in Chomsky normal form can derive a string w in at most $2n - 1$ steps! (Shown in Sipser textbook)

Knowing this, we can just simulate all the possible rule combinations for 2^n steps and see if any of the resulting strings matches w.

E_{CFG} decidable?

E_{CFG} decidable?

YES!

E_{CFG} decidable?

YES!

In this case, we just need to know if we can get from the start variable to a string with only terminal symbols.

1. Mark all terminal symbols in G
2. Repeat until no new variables get marked:
   2.1 Mark any variable A where G has the rule $A \rightarrow U_1U_2 \ldots U_k$ where U_i is a marked terminal/variable
3. If start variable is not marked, accept. Otherwise reject.

- $V = \{S\}$
- $T = \{0, 1\}$
- $P = \{S \rightarrow \epsilon \mid 0S0 \mid 1S1\}$ (abbrev. for $S \rightarrow \epsilon, S \rightarrow 0S0, S \rightarrow 1S1$)

ALL_{CFG} decidable?

ALL_{CFG} decidable?

Nope

ALL_{CFG} decidable?

Nope

Proof requires computation histories which are outside the scope of this course.

A_{LBA} decidable?

A_{LBA} decidable?

YES!

A_{LBA} decidable?

YES!

Remember a LBA has a finite tapes. Therefore we know:

1. A tape of length n where each cell can contain g symbols, you have g^n possible configurations.
2. The tape head can be in one of n positions and has q states yielding a tape that can be in qn configurations.
3. Therefore the machine can be in qng^n configurations.

A_{LBA} decidable?

YES!

Remember a LBA has a finite tapes. Therefore we know:

1. A tape of length n where each cell can contain g symbols, you have g^n possible configurations.
2. The tape head can be in one of n positions and has q states yielding a tape that can be in qn configurations.
3. Therefore the machine can be in qng^n configurations.

Lemma
If an LBA does not accept or reject in qng^n then it is stuck in a loop forever.

A_{LBA} decidable?

Decider for A_{LBA} will:

1. Simulate $\langle M \rangle$ on w for qng^n steps.
   1.1 if accepts, then accept
   1.2 if rejects, then reject
2. If neither accepts or rejects, means it's in a loop in which case, reject.

E_{LBA} decidable?

E_{LBA} decidable?

Nope

E_{LBA} decidable?

Nope

Proof requires computational history trick, a story for another time......

ALL_{LBA} decidable?

ALL_{LBA} decidable?

Nope

ALL_{LBA} decidable?

Nope

No standard proof for this, but let's look at a pattern:

ALL_{LBA} decidable?

Nope

No standard proof for this, but let's look at a pattern:

So we sort've figure that ALL_{LBA} isn't decidable because we know (assuming you believe me) ALL_{CFG} wasn't (though intuition is never sufficient evidence).

Decidability across grammar complexities

	DFA	*CFG*	*PDA*	*LBA*	*TM*
A	D	D	D	D	U
E	D	D	D	U	U
ALL	D	U	U	U	U

Eventually problems get too tough....

Rice theorem

The above proofs were somewhat repetitious...

...they imply a more general result.

Theorem (Rice's Theorem.)
Suppose that L *is a language of Turing machines; that is, each word in* L *encodes a TM. Furthermore, assume that the following two properties hold.*

(a) *Membership in* L *depends only on the Turing machine's language, i.e. if* $L(M) = L(N)$ *then* $\langle M \rangle \in \mathsf{L} \Leftrightarrow \langle N \rangle \in \mathsf{L}$.

(b) *The set* L *is "non-trivial," i.e.* $\mathsf{L} \neq \emptyset$ *and* L *does not contain all Turing machines.*

Then L *is a undecidable. (**Note: In an exam, you can't just say undecidable because of Rice's theorem.**)*

Un-/decidability practice problems

Available Undecidable languages

- $L_{Accept} = \left\{ \langle M, w \rangle \;\middle|\; M \text{ is a } TM \text{ and accepts } w \right\}.$
- $L_{HALT} = \left\{ \langle M \rangle \;\middle|\; M \text{ is a } TM \text{ and halts on } \varepsilon \right\}.$

Practice 1: Halt on Input

Is the language:

$$L_{HaltOnInput} = \left\{ \langle M, w \rangle \,\middle|\, M \text{ is a } TM \text{ and halts on } w \right\}.$$

Practice 2: L has fooling set

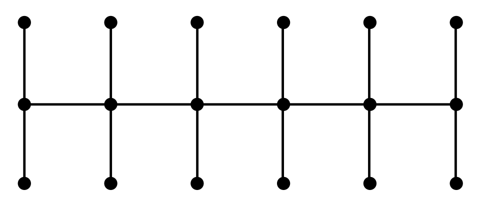
Is the language:

$$L_{HasFooling} = \left\{ \langle M \rangle \;\middle|\; M \text{ is a } TM \text{ and } L(M) \text{ has a fooling set } \right\}.$$

NP-Complete practice problems

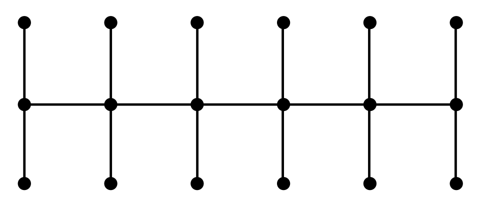
Practice: NP-Complete Reduction I

A centipede is an undirected graph formed by a path of length k with two edges (legs) attached to each node on the path as shown in the below figure. Hence, the centipede graph has $3k$ vertices. The **CENTIPEDE** problem is the following: given an undirected graph $G = (V, E)$ and an integer k, does G contain a centipede of $3k$ vertices as a subgraph? Prove that **CENTIPEDE** is **NP-Complete**.

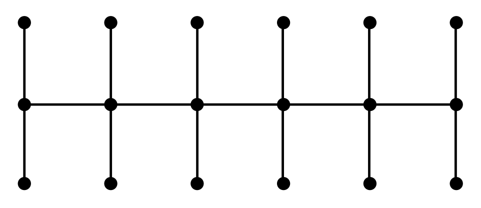


Practice: NP-Complete Reduction

What do we need to do to prove Centipede is NP-Complete?

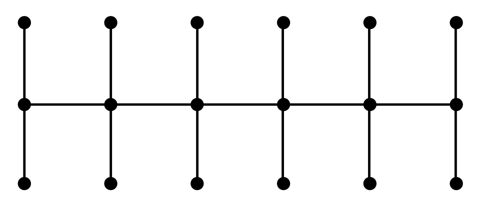


Prove Centipede is in NP:



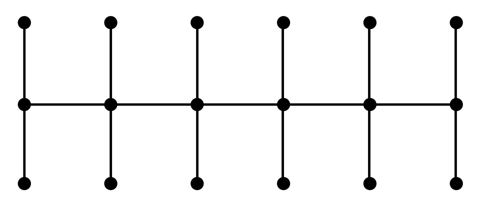
Practice: NP-Complete Reduction

Prove Centipede is in **NP-hard**:



Practice: NP-Complete Reduction

Prove Centipede is in NP-hard:



Hamiltonian Path: Given a graph G (either directed or undirected), is there a path that visits every vertex exactly once

$HC \leq_P Centipede$

Practice: NP-Complete Reduction I

A quasi-satisfying assignment for a 3CNF boolean formula Φ is an assignment of truth values to the variables such that at most one clause in Φ does not contain a true literal. Prove that it is NP-complete to determine whether a given 3CNF boolean formula has a quasi-satisfying assignment.

Practice: NP-Complete Reduction I

A quasi-satisfying assignment for a 3CNF boolean formula Φ is an assignment of truth values to the variables such that at most one clause in Φ does not contain a true literal. Prove that it is NP-complete to determine whether a given 3CNF boolean formula has a quasi-satisfying assignment.

Prove quasiSAT is in NP

Practice: NP-Complete Reduction I

A quasi-satisfying assignment for a 3CNF boolean formula Φ is an assignment of truth values to the variables such that at most one clause in Φ does not contain a true literal. Prove that it is NP-complete to determine whether a given 3CNF boolean formula has a quasi-satisfying assignment.

Prove quasiSAT is NP-hard

Practice: NP-Complete Reduction II

Prove quasiSAT is NP-hard

Prove quasiSAT is NP-hard

3SAT: Given a boolean formula in conjunctive normal form, with exactly three distinct literals per clause, does the formula have a satisfying assignment.

Good luck on the exam