UNIVERSITY OF BIRMINGHAM

School of Computer Science

Final Year - BSc Artificial Intelligence and Computer Science
Final Year – BSc Computer Science
Third Year – MSci Computer Science
Third Year – MEng Computer Science/Software Engineering
Final Year – BSc Mathematics & Computer Science
Third Year – MSci Mathematics & Computer Science
Final Year – BSc Computer Science with Study Abroad
Final Year – BSc Mathematics & Computer Science with Study Abroad
First Year – MSci Computer Science with Study Abroad
First Year – BSc Computer Science with Business Management
Final Year – BSc Computer Science with Industrial Year
Third Year – MEng Computer Science/Software Engineering with Industrial Year
Third Year – MSci Computer Science with Industrial Year

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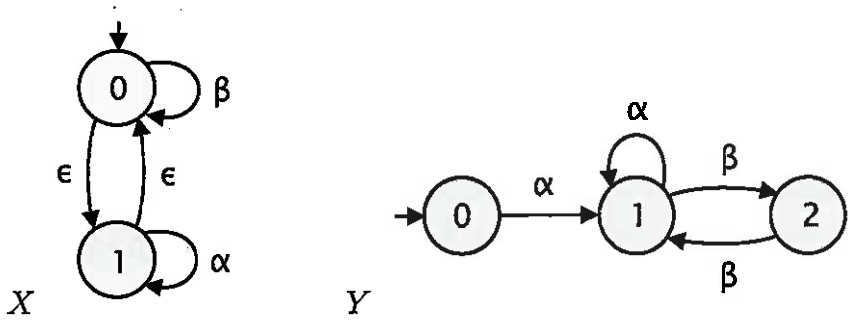
Computer-Aided Verification

Summer May/June Examinations 2017

Time allowed: 1 hour 30 minutes

[Answer ALL Questions]

1. Below are two labelled transition systems (LTSs) X and Y, with state spaces $\{0, 1\}$ and $\{0, 1, 2\}$, respectively.



(a) Draw the LTS representing the parallel composition $X \,||_{\{\alpha,\beta\}}\, Y$, where the component LTSs synchronise on actions α and β.

[7%]

(b) For each of the following properties, explain how it can be expressed in linear temporal logic (LTL), with respect to the LTS constructed for part (a), state whether the property is satisfied in the LTS and, if it is not, give a counterexample.

(i) Y never reaches state 2;

(ii) whenever Y is in state 2, the state of Y is positive immediately afterwards;

(iii) on any execution where the states of both X and Y are 0 only finitely often, X and Y must both eventually reach and stay in state 1.

(iv) a state where X is in state 1 is always preceded immediately by a state where X is in state 0.

[10%]

(c) For each of the four linear-time properties from part (b), state which class of properties it belongs to (invariant, safety, liveness) and justify your answer.

[8%]

2. (a) Explain what it means for two LTL formulae to be *equivalent*. Then explain (formally or informally) why the following equivalence holds:

$$\Box\Diamond\psi_1 \vee \Box\Diamond\psi_2 \equiv \Box\Diamond(\psi_1 \vee \psi_2)$$

[9%]

(b) Either prove or disprove each of the following proposed LTL equivalences. You can use, where needed, the equivalence from part (a), or known equivalences for individual temporal operators in LTL (e.g., $\Box\psi \equiv \neg\Diamond\neg\psi$) or standard equivalences for propositional logic.

(i) $(\Diamond\Box a) \wedge (\Diamond\Box\neg b) \equiv \neg\Box\Diamond(a \rightarrow b)$

(ii) $(\Diamond\neg c) \vee (\Diamond\neg d) \vee (\Diamond\Box a) \vee (\Diamond\Box b) \equiv (\Diamond\neg(c \wedge d)) \vee (\Diamond\Box(a \vee b))$

[16%]

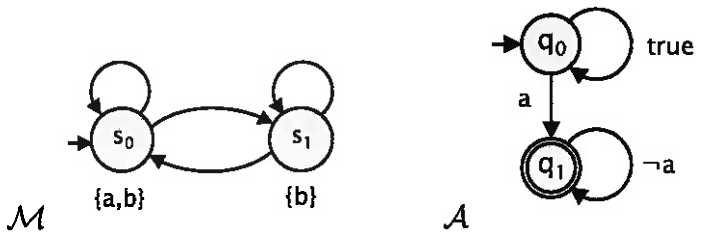
3. (a) Explain the difference between a nondeterministic finite automaton (NFA) and a nondeterministic Büchi automaton (NBA).

[5%]

(b) Draw an NFA for the regular safety property represented by the LTL formula $\Box(b \rightarrow \bigcirc(a \wedge \bigcirc a))$.

[6%]

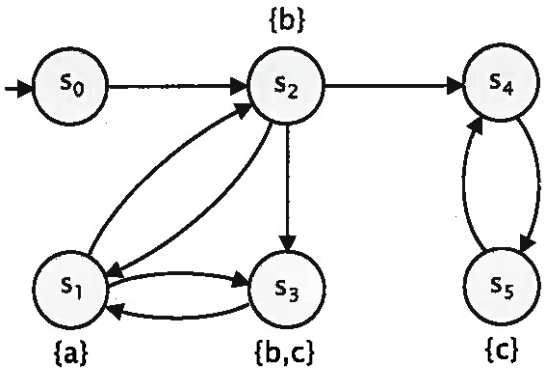
(c) Below are an LTS $\mathcal{M}$ and an NBA $\mathcal{A}$:



Give an LTL formula ψ such that the NBA $\mathcal{A}$ represents the negated formula $\neg\psi$. Then, illustrate the full LTL model checking procedure to show whether $\mathcal{M}$ satisfies ψ. Finally, give an explanation, in terms of the original LTS $\mathcal{M}$, as to why ψ is or is not satisfied.

[14%]

4. (a) Illustrate the application of the CTL model checking algorithm to determine whether the LTS below satisfies the CTL formula $\phi = \exists(\neg a \, \mathrm{U} \, (\forall\Diamond c)) \wedge \forall\bigcirc(b \vee \neg c)$, after first converting it to existential normal form.



[12%]

(b) Below is a formula expressed in the temporal logic CTL*, which, like CTL, allows both existential ($\exists$) and universal ($\forall$) quantification over paths and, like LTL, allows temporal operators (e.g., $\Box$ and $\Diamond$) to be combined to express properties of paths.

$$\exists\bigcirc\forall(\Box\Diamond(\exists\bigcirc(c \wedge \neg b)))$$

State whether or not the formula is satisfied in the LTS from part (a), justifying your answer. Then propose a way to model check this formula on an arbitrary LTS.

[13%]

Do not complete the attendance slip, fill in the front of the answer book or turn over the question paper until you are told to do so

Important Reminders

- Coats/outwear should be placed in the designated area.
- Unauthorised materials (e.g. notes or tippex) must be placed in the designated area.
- Check that you do not have any unauthorised materials with you (e.g. in your pockets, pencil case).
- Mobile phones and smart watches **must** be switched off and placed in the designated area or under your desk. They must not be left on your person or in your pockets.
- You are not permitted to use a mobile phone as a clock. If you have difficulty seeing a clock, please alert an Invigilator.
- You are not permitted to have writing on your hand, arm or other body part.
- Check that you do not have writing on your hand, arm or other body part – if you do, you must inform an Invigilator immediately
- Alert an Invigilator immediately if you find any unauthorised item upon you during the examination.

Any students found with non-permitted items upon their person during the examination, or who fail to comply with Examination rules may be subject to Student Conduct procedures.