FOR INTERNAL SCRUTINY (date of this version: 31/3/2025)

UNIVERSITY OF EDINBURGH

COLLEGE OF SCIENCE AND ENGINEERING

SCHOOL OF INFORMATICS

INFR11248

Monday 23rd December 1963

20:00 to 23:29

INSTRUCTIONS TO CANDIDATES

1. **Note that ALL QUESTIONS ARE COMPULSORY.**
2. **DIFFERENT QUESTIONS MAY HAVE DIFFERENT NUMBERS OF TOTAL MARKS. Take note of this in allocating time to questions.**
3. **This is a NOTES PERMITTED, CALCULATORS NOT PERMITTED examination.**

   Candidates may consult up to THREE A4 pages (6 sides) of notes.

   CALCULATORS MAY NOT BE USED IN THIS EXAMINATION.

Year 4 Courses

Convener: ITO-Will-Determine
External Examiners: ITO-Will-Determine

THIS EXAMINATION WILL BE MARKED ANONYMOUSLY

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There are 6 questions. You can earn 50 marks total.

1. In our garage is a light with two switches – one near each door. Each of the two switches has an *up* and a *down* position. We can perform 4 actions on these switches: $1^{\uparrow}$, $1^{\downarrow}$, $2^{\uparrow}$ and $2^{\uparrow}$, switching switches 1 and 2 to the up and down positions, respectively. Naturally, action $1^{\uparrow}$ cannot be performed if the switch is already in the up position. We also allow an action *light* of observing that the light is on. This action does not change the state of the light. In the beginning, the light is off, and both switches are down. If we toggle any switch, the light toggles between off and on.

   Give a recursive specification of this system in CCS, ACP or CSP, using the five visible actions indicated above. [*6 marks*]

2. Present a process (as a process graph or as a CCS, ACP or CSP expression) that satisfies the HML formula

$$[a]\langle b\rangle\top \wedge \langle a\rangle[b]\neg\langle c\rangle\top \wedge \langle a\rangle[b]\langle c\rangle\top\ .$$ [*3 marks*]

3. Consider transition systems labelled (only) with the specific actions b, c and d.

   Call a b-labelled transition from state s to state s' in a labelled transition system *encumbered* if there is also a c-labelled transition enabled in state s.

   Let f be the selective renaming operator that changes the label of any encumbered b-labelled transition into d, and leaves everything else as it was.

   (a) Give a structural operational semantics of this operator. [*3 marks*]

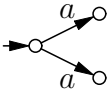
   (b) Is strong completed trace equivalence a congruence for f? [*2 marks*]

   (c) Is strong bisimilarity a congruence for f? [*2 marks*]

   In both cases support your verdict with a counterexample or a convincing argument.

   (d) Formulate a judgement $f(P) \models \varphi$ that tells us that after applying operator f to an arbitrary process P we will never reach a state in which there is a choice to be made between proceeding with a b or a c transition. Here φ is an LTL or a CTL formula; you may assume the standard De Nicola-Vaandrager translation from labelled transition systems to Kripke structures used to interpret LTL and CTL formulas on states in labelled transition systems. [*2 marks*]

   (e) Explain your choice in (d) between an LTL and a CTL formula. [*2 marks*]

4. Consider a new modality to be added to CTL: $\mathbf{E}_2\mathbf{X}\phi$; it holds in a state s if this state has at least two distinct successor states in which the formula ϕ is valid. So, for example, the process 

satisfies $\mathbf{E}_2\mathbf{X}a$. Can this new modality be expressed in the traditional CTL? Show how, or why not. [*3 marks*]

5. Consider the CCS expression $P = ((b.c.d)|(\overline{c} + \tau.d))\backslash c$ (eliding trailing **0**s).

   (a) Draw a process graph representing this process. [*3 marks*]

   (b) Give a process Q, reachable from P, from where a τ-transition is possible that results from synchronising c and $\overline{c}$. [*2 marks*]

   (c) Derive this τ-transition $Q \xrightarrow{\tau} R$ formally from the rules of the structural operational semantics of CCS. [*3 marks*]

   (d) Draw a Petri net representing P. [*3 marks*]

   (e) What are the weak completed traces of P? [*2 marks*]

   (f) What are the strong partially-ordered completed traces of P? [*2 marks*]

   (g) Give an ACP expression which is strongly bisimilar with P and has the same strong partially-ordered completed traces as P.
   Hint: You expression should have only one occurrence of the operator $+$. [*2 marks*]

   (h) Give a CSP expression which is strongly bisimilar with P and has the same strong partially-ordered completed traces as P.
   Hint: You expression should have only one occurrence of $\sqcap$ or $\Box$. [*2 marks*]

   (i) What is the minimal number of states of a process that is strongly bisimilar to P? Give the smallest CCS representation of such a processes. [*2 marks*]

   (j) What is the minimal number of states of a process that is branching bisimilar to P? Give the smallest CCS representation of such a processes. [*2 marks*]

6. (**Hard**; do this only if you have time left)

   (a) Given an example of two processes (possibly presented as states in an LTS) that are

      i. branching bisimilar

      ii. as well as divergence-preserving weak bisimilar

      iii. but that are not weakly divergence-preserving branching bisimilar. [*2 marks*]

   (b) Give a CTL_{-X} formula that holds for only one those processes. [*2 marks*]