CSIE 5452, Fall 2018 — Midterm Solution

Name: ____________________ SID: ____________________ Email: ____________________

1 True or False (8pts)

Determine whether the following statements are true or false by circling the correct choice. No explanation is required. No partial credit will be given.

T F 1. (1pt) A current vehicle is more like a distributed system (there are many ECUs, and each of them executes few tasks) rather than a centralized system (there are few ECUs, and each of them executes many tasks).

T F 2. (1pt) The following scenario achieves level-4 autonomy: a driver can safely turn the attention away from the driving tasks, but the driver must be prepared to intervene, when called upon by the vehicle.

T F 3. (1pt) A simulated annealing approach can guarantee to find an optimal solution.

T F 4. (1pt) For safety applications, Dedicated Short Range Communications (DSRC) needs routing, and it is supported by the Internet Protocol (IP).

T F 5. (1pt) The standard of 5G Cellular Vehicle-to-Everything (C-V2X) must have a base station to achieve communication.

T F 6. (1pt) Besides the location, a Global Positioning System (GPS) can also provide the current time.

T F 7. (1pt) Without human intervention, close-loop control can provide better quality of control than open-loop control in most cases.

T F 8. (1pt) Regarding the errors considered in a Proportional Integral Derivative (PID) controller, the proportional term is mainly to consider the current error, the integral term is mainly to consider the accumulated past error, and the derivative term is mainly to predict the future error.

Answer: T, F, F, F, F, T, T, T.

2 Sorting and Matching-Up (16pts)

Sort the items by the given criteria (all questions except the last one) or match up the asked items (the last question). Given n items, your answer should be a sequence of n numbers, *e.g.*, 123 for three items or 4321 for four items. No explanation is required.

__________ 1. (2pts) Sensing range from high (good) to low (bad): (1) automotive-use camera, (2) automotive-use radar, (3) automotive-use ultrasonic sensor.

__________ 2. (2pts) Robustness against snow, fog, or rain, from high (good) to low (bad): (1) automotive-use camera (2) automotive-use radar, (3) automotive-use lidar.

__________ 3. (2pts) Resolution from high (good) to low (bad): (1) automotive-use camera (2) automotive-use radar, (3) automotive-use lidar.

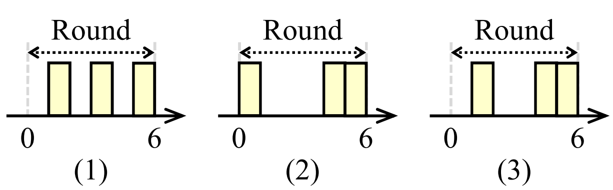
__________ 4. (2pts) The chronological (sort by when things happen) reaction steps of a vehicle to an event: (1) actuation, (2) control, (3) decision and planning, (4) sensing, (5) perception.

__________ 5. (2pts) The planning hierarchy from high-level to low-level: (1) route planning, (2) behavioral planning, (3) trajectory planning and motion planning, (4) low-level feedback control.

__________ 6. (2pts) There are four messages with their <u>*true*</u> worst-case response times $[10, 20, 30, 40]$. There are three timing analysis approaches analyzing these messages with their results: Approach (1) gets $[10, 20, 30, 39]$, Approach (2) gets $[15, 25, 35, 45]$, Approach (3) gets $[20, 30, 40, 50]$. Sort the three approaches from good to bad (in the context of this course).

__________ 7. (2pts) As shown in the figure below, there are three schedules for an asynchronous message in a Time Division Multiple Access (TDMA) based protocol. Sort the three schedules from good (smaller worst-case response time) to bad (larger worst-case response time).

__________ 8. (2pts) The Advanced Driver-Assistance Systems (ADAS) preventing the wheels from from loss of traction when braking, acceleration, and turning: (1) Electronic Stability Control (ESC), (2) Traction Control System (TCS), (3) Anti-Lock Braking System (ABS).



Answer: 123, 231, Free, 45321, 1234, 231, 132, 321.

3 Reasoning (20pts)

1. (2pts) What is the major reason that a simulated annealing approach may replace the current solution by a worse solution?

   Answer: It provides a chance to reach a global optimum; otherwise, it will be trapped at a local optimum.

2. (2pts) List <u>*two*</u> reasons that the Controller Area Network (CAN) is still the most popular in-vehicular network protocol.

   Answer: Cheap, simple, deterministic, and/or used for a long time without major issues.

3. (4pts) This is the equation for the CAN timing analysis:

$$Q_i = B_i + \sum_{\forall j, P_j < P_i} \left\lceil \frac{Q_i + \tau}{T_j} \right\rceil C_j, \tag{1}$$

   where the detailed definitions are provided in Question 4. If we replace B_i by "the largest transmission time of ALL messages", does the timing analysis still guarantee that a message will respond before its analyzed worst-case response time? Explain the reason.

   Answer: Yes. It is more pessimistic, but pessimism, implying overestimation, is fine.

4. (4pts) What is the major benefit of packing multiple signals into a CAN message?

   Answer: The header, compared with the payload, is not a small portion, so the signal packing can significantly increase the data efficiency, reduce the bandwidth, and save the header bits.

5. (4pts) In Homework 2, we implement a simulated annealing approach for priority assignment of CAN messages. What is the reason that it is better to "swap the priorities of two random messages" rather than "assign the priority of a random message to another random value"?

   Answer: It is not allowed for two messages to have the same priority.

6. (4pts) If a vehicle has the feature of object detection, explain (1) why the feature plus mapping can assist localization and (2) why the feature plus localization can assist mapping.

   Answer: When the vehicle detects an object and its relative coordinates, (1) if the map has the coordinates of the object, the vehicle can compute its own location; (2) if the vehicle has its own location, it can compute the coordinates of the object and then add or verify the object in the map.

4 CAN Timing Analysis (20pts)

Given a set of periodic messages μ_0, μ_1, μ_2 with their priorities, transmission times, and periods as follows:

Message	Priority (P_i)	Transmission Time (C_i) (msec)	Period (T_i) (msec)
μ_0	0	10	40
μ_1	1	30	100
μ_2	2	20	75

The worst-case response time R_i of μ_i can be computed as

$$R_i = Q_i + C_i, \tag{2}$$

and

$$Q_i = B_i + \sum_{\forall j, P_j < P_i} \left\lceil \frac{Q_i + \tau}{T_j} \right\rceil C_j, \tag{3}$$

where $\tau = 0.1$, Q_i is the worst-case waiting time of μ_i, B_i is the maximum blocking time of μ_i, which is equal to the maximum transmission time of all lower or same (μ_i itself) priority messages.

1. (12pts) Perform the timing analysis for μ_1 by completing the following table. No explanation is required. *Reminder*: we are NOT asking μ_0.

   Answer: Q_1 is computed as follows:

Iteration	LHS (Q_1)	B_1	j	$Q_1 + \tau$	T_j	$\left\lceil \frac{Q_1+\tau}{T_j} \right\rceil$	C_j	RHS	Stop?
1	30	30	0	30.1	40	1	10	40	No
2	40	30	0	40.1	40	2	10	50	No
3	50	30	0	50.1	40	2	10	50	Yes

   $R_1 = Q_1 + C_1 = 50 + 30 = 80$ (msec).

2. (8pts) Perform the timing analysis for μ_2 by completing the following table. No explanation is required.

   Answer: Q_2 is computed as follows:

Iteration	LHS (Q_2)	B_2	j	$Q_2 + \tau$	T_j	$\left\lceil \frac{Q_2+\tau}{T_j} \right\rceil$	C_j	RHS	Stop?
1	20	20	0 1	20.1	40 100	1 1	10 30	60	Yes (Constraint Violation)

   The RHS is 60, and $60 + C_2 = 60 + 20 = 80 > T_2 = 75$. Therefore, the timing analysis returns a constraint violation.

5 TDMA Timing Analysis (12pts)

Follow the assumptions (each time slot has the same length, each time slot serves exactly one frame, and a frame is transmitted only if the whole time slot is available) in the lecture and Homework 2 and answer the following questions for the "asynchronous" message with the frame arrival pattern $(4, 10, 0, 3, 5, 6)$ and the schedule pattern $(2, 5, 1, 2)$. EXCEPT the last question, no explanation is required.

1. (2pts) Duplicate the schedule pattern (hint: $(4, 10, 1, 2, \ldots)$).

   Answer: $(4, 10, 1, 2, 6, 7)$.

2. (1pt) Duplicate the arriving times of frames in the frame arrival pattern but fix $m = 4$ and $p = 10$.

   Answer: $(4, 10, 0, 3, 5, 6, 10, 13, 15, 16)$.

3. (1pt) Duplicate the starting times of time slots in the schedule pattern but fix $n = 4$ and $q = 10$.

   Answer: $(4, 10, 1, 2, 6, 7, 11, 12, 16, 17)$.

4. (4pts) Complete the following table.

   Answer:

k	$\max_{1\le j\le n}(s_{j+k} - s_j)$	=	$\min_{1\le i\le m}(a_{i+k-1} - a_i)$	=	(Column-3) − (Column-5)
1	$\max_{1\le j\le 4}(s_{j+1} - s_j)$	4	$\min_{1\le i\le 4}(a_i - a_i)$	0	4
2	$\max_{1\le j\le 4}(s_{j+2} - s_j)$	5	$\min_{1\le i\le 4}(a_{i+1} - a_i)$	1	4
3	$\max_{1\le j\le 4}(s_{j+3} - s_j)$	9	$\min_{1\le i\le 4}(a_{i+2} - a_i)$	3	6
4	$\max_{1\le j\le 4}(s_{j+4} - s_j)$	10	$\min_{1\le i\le 4}(a_{i+3} - a_i)$	6	4

5. (4pts) Explain the scenario that the worst-case happens (which frame misses which time slot, and which frame suffers the worst case).

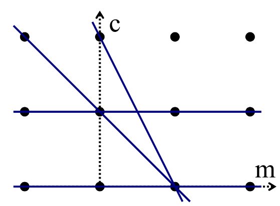
   Answer: The second frame (whose arrival time is "3") misses the second time slot (whose starting time is "2"), and the fourth frame (whose arrival time is "6") suffers the worst case. When the second frame's arrival time is aligned with the second time slot's starting time, it means that the whole frame arrival pattern is shifted to left by 1. Thus, the fourth frame is shifted to arrive at 5 and served at 11, so the waiting time is 6.

6 Hough Transform (8pts)

Perform the Hough Transform between the (x, y)-space and the (m, c)-space, where $y = mx + c$. No explanation is required.

1. (4pts) Given $(0, 0), (0, 1), (1, 1), (2, 2)$ in the (x, y)-space, draw their corresponding lines in the (m, c)-space.

   Answer:

2. (2pts) Write down the coordinates of the point which receives the most "votes" in the (m, c)-space.

   Answer: $(1, 0)$.

3. (2pts) Given the coordinates above in the (m, c)-space, write down the corresponding equation in the (x, y)-space.

   Answer: $y = x$.

7 MILP Linearization (12pts)

Prove the equivalence or transform constraints to linear forms which are required by the Mixed Integer Linear Programming (MILP). Note that "$\Longleftrightarrow$" denotes "equivalence" and "$\wedge$" denotes "logical conjunction" (AND).

1. (4pts) Given α, β which are binary variables, prove

$$\alpha + \beta \neq 1 \Longleftrightarrow \alpha \leq \beta \wedge \beta \leq \alpha.$$

Answer: It is equivalent as LHS and RHS are the same in all cases in the following truth table:

α	β	LHS	$\alpha \leq \beta$	$\beta \leq \alpha$	RHS	LHS=RHS?
0	0	T	T	T	T	T
0	1	F	T	F	F	T
1	0	F	F	T	F	T
1	1	T	T	T	T	T

Note that you can also prove this by explaining that both sides are equivalent to $\alpha = \beta$.

2. (8pts) Given α, β, γ which are binary variables, transform $\alpha + \beta + \gamma \neq 1$ to MILP constraints and prove the equivalence.

Answer:

$$\alpha + \beta + \gamma \neq 1 \Longleftrightarrow \alpha \leq \beta + \gamma \wedge \beta \leq \alpha + \gamma \wedge \gamma \leq \alpha + \beta.$$

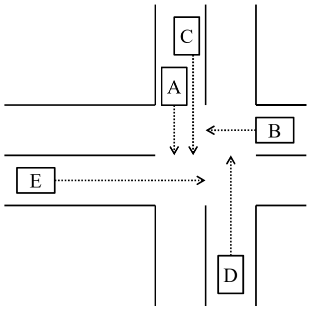
It can be proved by the following truth table:

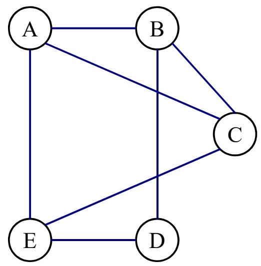
α	β	γ	LHS	$\alpha \leq \beta + \gamma$	$\beta \leq \alpha + \gamma$	$\gamma \leq \alpha + \beta$	RHS	LHS=RHS?
0	0	0	T	T	T	T	T	T
0	0	1	F	T	T	F	F	T
0	1	0	F	T	F	T	F	T
0	1	1	T	T	T	T	T	T
1	0	0	F	F	T	T	F	T
1	0	1	T	T	T	T	T	T
1	1	0	T	T	T	T	T	T
1	1	1	T	T	T	T	T	T

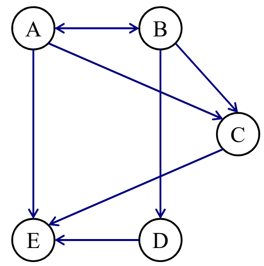
Note that, if you replace α, β, γ by $(1-\alpha'), (1-\beta'), (1-\gamma')$, respectively, you will see the equivalence in Homework 2.

8 Intersection Management (16pts)

The scenario is shown in the left figure. Each vehicle goes straight in the intersection. The estimated arrival times of Vehicles A, B, C, D, and E are, 0, 0, 5, 5, and 10 time-units from now, respectively. Each vehicle needs 5 time-units to go through the intersection.







1. (2pts) Draw the graph for spatial conflict in the middle figure. There should be an undirected edge between two vertices (vehicles) if and only if they have a trajectory conflict. No explanation is required.

   Answer: The middle figure.

2. (2pts) Draw the graph for temporal conflict in the right figure. An edge in the graph for spatial conflict should become one or two directed edges. No explanation is required.

   Answer: The right figure.

3. (4pts) Based on the graph for temporal conflict, find a passing order which minimizes the number of phases (rounds) needed for all vehicles to go through the intersection. Note that, in this case, the objective is equivalent to minimize the time that the last vehicle leaves the intersection. Explain why the solution is optimal, given the graph for temporal conflict.

   Answer: {A}, {B}, {C,D}, {E} or {B}, {A}, {C,D}, {E} or {B}, {A,D}, {C}, {E}. We only need to remove the cycle between A and B. No matter which one is picked first, there is still a path (A,B,C,E) or (B,A,C,E) in the graph, implying at least 4 phases.

4. (8pts) Now, consider the same scenario but do NOT consider the three questions above and their graphs. Can you find another passing order which further minimizes the number of phases (rounds) needed for all vehicles to go through the intersection? If yes, show the passing order and explain why the graph for temporal conflict cannot lead to the passing order. If no, prove the solution in Question 8.3 is optimal to the scenario (Question 8.3 is to prove the solution is optimal, given the graph for temporal conflict).

   Answer: Yes. {A}, {C,D}, {B,E}. The graph for temporal conflict limits Vehicle B to enter the intersection earlier than Vehicles C and D as Vehicle B has an earlier estimated arrival time. However, if Vehicle A enters the intersection first and delays Vehicle B, the earliest entering time of Vehicle B is 5, same as those of Vehicles C and D. As a result, we actually have the flexibility to schedule Vehicles C and D first and lead to a better solution.