

PRINT Your Name: \_\_\_\_\_

PRINT Your Student ID: \_\_\_\_\_

You have 110 minutes. There are 7 questions of varying credit. (100 points total)

Question:	1	2	3	4	5	6	7	Total
Points:	9	12	14	16	13	14	22	100

For questions with **circular bubbles**, you may select only one choice.

- Unselected option (Completely unfilled)
- Don't do this (it will be graded as incorrect)
- Only one selected option (completely filled)

For questions with **square checkboxes**, you may select one or more choices.

- You can select
- multiple squares
- Don't do this (it will be graded as incorrect)

Anything you write outside the answer boxes or you ~~cross out~~ will not be graded. If you write multiple answers, your answer is ambiguous, or the bubble/checkbox is not entirely filled in, we will grade the worst interpretation.

**Honor Code:** Read the honor code below and sign your name.

I understand that I may not collaborate with anyone else on this exam, or cheat in any way. I am aware of the Berkeley Campus Code of Student Conduct and acknowledge that academic misconduct will be reported to the Center for Student Conduct and may further result in, at minimum, negative points on the exam.

SIGN your name: \_\_\_\_\_



## Q1 *Potpourri*

(9 points)

Q1.1 (2 points) In Project 1 (Traceroute), which is **not** a reason we send 3 probes for each TTL?

- Because probes could be dropped.
- Because responses to probes could be dropped.
- Because there could be multiple paths to the destination.
- Because there could be routing loops in the network.

Q1.2 (2 points) In Project 1 (Traceroute), when a traceroute **probe** is sent across a link on the network, which headers are on the packet? Select all that apply.

- TCP header
- IP header
- None of the above
- UDP header
- ICMP header

Q1.3 (2 points) What does this line from Project 2 (Routing) do?

```
self.table[dst] = TableEntry(dst=dst,  
                             port=self.table[dst].port,  
                             latency=INFINITY,  
                             expire_time=api.current_time()+self.ROUTE_TTL)
```

- Poisons an expired route.
- Accepts an advertisement from a router.
- Sends a poison reverse advertisement.
- Enables split horizon.

Q1.4 (1 point) True or false: The modern internet uses circuit switching, because Layer 4 guarantees reliable delivery.

- True
- False

Suppose CodaBot and EvanBot are sharing a link with capacity 10 Gbps. CodaBot's peak demand is 6 Gbps, and EvanBot's peak demand is 7 Gbps. We have no other information about their demands.

Q1.5 (1 point) If we use statistical multiplexing to allocate bandwidth, is the 10 Gbps link sufficient to satisfy both CodaBot and EvanBot's demands?

- Always
- Sometimes
- Never

Q1.6 (1 point) If we **do not** use statistical multiplexing to allocate bandwidth, is the 10 Gbps link sufficient to satisfy both CodaBot and EvanBot's demands?

- Always
- Sometimes
- Never

## Q2 IP Header

(12 points)

Consider a link with MTU (maximum transmission unit) of 520 bytes. A router wants to send an IPv4 packet of size 8020 bytes (20 bytes of header and 8000 bytes of payload) along the link.

Q2.1 (2 points) If the router fragments this packet, what is the minimum number of fragments that must be sent along the link?

- 2       4       8       15       16       20

Q2.2 (2 points) In total, how many extra bytes are sent along the link due to fragmentation (compared to sending the 8020 bytes as a single unit)?

- 0       20       150       300       8000       8020

Q2.3 (3 points) Which fields of the IP header are the same in every fragment of this packet? Select all that apply.

- Source IP       Identification       Fragment Offset  
 Destination IP       Flags       None of the above

Q2.4 (2 points) How would the router handle the 8020-byte packet?

- User packet       Control traffic       Punt traffic

Q2.5 (3 points) IPv6 would drop this packet instead of fragmenting the packet. Select all true statements about this design choice.

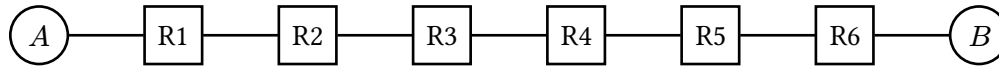
- This improves performance at the routers.  
 This eliminates the need for some fields in the IP header.  
 The sender cannot recover from packet loss, so the recipient will never receive the data.  
 None of the above

**Q3 Links****(14 points)**

Consider the topology below, where each link has bandwidth 10 Gbps, and propagation delay 2 sec.

For all subparts:

- A router must receive all bits of a payload before sending that payload along the next link.
- Queue sizes are infinite, and queues are processed in FIFO order.



Q3.1 (2 points) For this subpart, assume there is no other traffic on the network.

$A$  sends a single 50 Gbit packet to  $B$ . What is the packet delay, in seconds?

- 14    
  21    
  28    
  35    
  42    
  47    
  49    
  56

Q3.2 (3 points) For this subpart, assume that, at the moment  $A$  starts sending the 50 Gbit packet to  $B$ , there is a queue of 300 Gbits at router  $R5$ . How does the packet delay (in seconds) change in this scenario, compared to the delay from the previous subpart?

- Decrease by 7                     
  Increase by 7                     
  No change  
 Decrease by 10                     
  Increase by 10                     
  Not enough information  
 Decrease by 30                     
  Increase by 30

Q3.3 (3 points) Suppose we change the propagation delay of each link from 2 sec to  $x$  sec. The bandwidth is unchanged at 10 Gbps.  $A$  sends a single 50 Gbit packet to  $B$ .

Select the inequality that describes when the packet delay would be affected by a 300 Gbit queue at  $R5$  (compared to the case where there is no queue at  $R5$ ).

- $x < 1$                      
   $x < 2$                      
   $x < 3$                      
   $x > 4$                      
   $x < 5$   
  $x > 1$                      
   $x > 2$                      
   $x > 3$                      
   $x > 4$                      
   $x > 5$   
 The packet delay is never affected by the queue, for any value of  $x$ .  
 The packet delay is always affected by the queue, for any value of  $x$ .

Q3.4 (3 points) Suppose we change the bandwidth of each link from 10 Gbps to  $y$  Gbps. The propagation delay is unchanged at 2 sec.  $A$  sends a single 50 Gbit packet to  $B$ .

Select the inequality that describes when the packet delay would be affected by a 300 Gbit queue at  $R5$  (compared to the case where there is no queue at  $R5$ ).

- $y < 5$                      
   $y < 7$                      
   $y > 10$                      
   $y < 14$                      
   $y < 30$   
  $y > 5$                      
   $y > 7$                      
   $y > 10$                      
   $y > 14$                      
   $y > 30$   
 The packet delay is never affected by the queue, for any value of  $y$ .  
 The packet delay is always affected by the queue, for any value of  $y$ .

(Question 3 continued...)

Q3.5 (1 point) What is the bandwidth-delay product of each link?

- |                               |                              |                                |
|-------------------------------|------------------------------|--------------------------------|
| <input type="radio"/> 20 Gbps | <input type="radio"/> 5 Gbps | <input type="radio"/> 0.2 Gbps |
| <input type="radio"/> 20 Gbit | <input type="radio"/> 5 Gbit | <input type="radio"/> 0.2 Gbit |
| <input type="radio"/> 20 sec  | <input type="radio"/> 5 sec  | <input type="radio"/> 0.2 sec  |

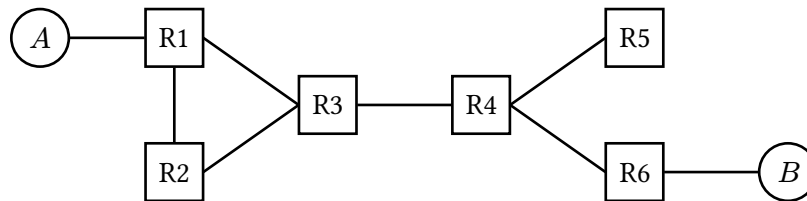
Q3.6 (2 points) EvanBot suggests implementing reliability in the routers. In which scenarios would this be a good idea?

- Always, because the suggestion follows the end-to-end principle.
- In scenarios where EvanBot cares about performance.
- In scenarios where EvanBot cares about correctness, but not performance.
- Never, because the suggestion violates the end-to-end principle.

**Q4 Distance-Vector**

**(16 points)**

Consider running the distance-vector algorithm from lecture on this topology. All unlabeled links cost 1.



Assumptions:

- At  $t = 0$ , all forwarding tables are empty.
- At  $t = 1$ , static routes are installed.
- At every time step starting at  $t = 2$ , each router (1) expires routes, then (2) processes advertisements and updates its table, then (3) sends out advertisements.
- Propagation delay is negligible, i.e. an advertisement sent out at  $t = 2$  can be processed at  $t = 3$ .
- Routing table entries expire after 5 seconds of receiving no advertisements.
- Split horizon, poison reverse, and route poisoning are disabled.
- All costs 16 or greater are considered infinite.

Q4.1 (2 points) What is the first time step where, after processing advertisements at that time step, every router has at least one entry in its forwarding table?

- $t = 1$      
   $t = 2$      
   $t = 3$      
   $t = 4$      
   $t = 5$      
   $t = 6$

Q4.2 (2 points) What is the first time step where, after processing advertisements at that time step, every router has two entries in its forwarding table?

- $t = 1$      
   $t = 2$      
   $t = 3$      
   $t = 4$      
   $t = 5$      
   $t = 6$

Some time later, the network has converged. After convergence, host  $A$  goes down.

Q4.3 (3 points) For the next two subparts, every router except **R4** expires its route to  $A$ .

Which router(s) will eventually have a cost-16 entry for  $A$ ? Select all that apply.

- R1     
  R2     
  R3     
  R4     
  R5     
  R6     
  None

Q4.4 (2 points) Which modification(s) will fix the problem in the previous subpart, so that no routers have a cost-16 entry for  $A$ ? Consider each modification independently.

- Enable split horizon.     
  None of the above  
 Enable poison reverse.

Q4.5 (3 points) Again, consider the scenario where the network converges, and then host  $A$  goes down.

For this subpart only, every router except **R2** expires its route to  $A$ .

Which router(s) will eventually have a cost-16 entry for  $A$ ? Select all that apply.

- R1     
  R2     
  R3     
  R4     
  R5     
  R6     
  None

(Question 4 continued...)

Q4.6 (4 points) Which modification(s) will fix the problem in the previous subpart, so that no routers have a cost-16 entry for  $A$ ? Consider each modification independently.

- Enable split horizon.
- Enable poison reverse.
- When  $A$  goes down, delete the R2-to-R3 link.
- When  $A$  goes down, delete the R1-to-R2 link.
- None of the above

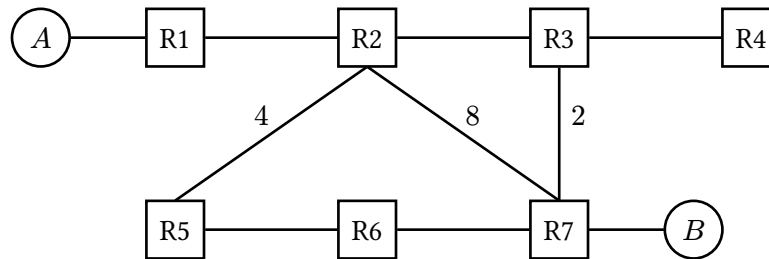
### Q5 Link-State

(13 points)

Consider running the link-state algorithm from lecture on the topology below.

Link costs correspond to packet travel times. All unlabeled links cost 1.

Assume there are no network errors, all routers use the same shortest-path algorithm, and advertisements are timestamped (as seen in lecture).



The routers exchange advertisements using this process:

- At  $t = 0$ , every router sends out hello messages to direct neighbors.
- As soon as a router knows about a neighbor, the router floods that information. For example, at  $t = 2$ , R3 sends an advertisement that says R3 and R7 are neighbors.
- At each time step, every router (1) processes advertisements, then (2) sends out any necessary advertisements.
- For this question, ignore periodically re-sending advertisements, i.e. assume all advertisements are sent just once.

Q5.1 (3 points) After processing advertisements at  $t = 2$ , which statements are true? Select all that apply.

- R1 knows that R1 and R2 are neighbors.
- R1 knows that R2 and R3 are neighbors.
- R1 knows that R2 and R5 are neighbors.
- None of the above

Q5.2 (3 points) After processing advertisements at  $t = 5$ , which statements are true? Select all that apply.

- R6 knows that R1 and R2 are neighbors.
- R6 knows that R2 and R3 are neighbors.
- R6 knows that R2 and R5 are neighbors.
- None of the above

Q5.3 (2 points) What is the first time step where R6 **receives** a duplicate advertisement about R3 and R4 being neighbors?

- $t = 3$
- $t = 4$
- $t = 5$
- $t = 6$
- $t = 7$
- $t = 8$
- R6 never receives a duplicate advertisement.

(Question 5 continued...)

Q5.4 (2 points) What is the first time step where R6 **sends** a duplicate advertisement about R3 and R4 being neighbors?

- $t = 3$         $t = 4$         $t = 5$         $t = 6$         $t = 7$         $t = 8$
- R6 never sends a duplicate advertisement.

Q5.5 (2 points) In total, how many times does R1 receive an advertisement about R6 and R7 being neighbors?

- 0       1       2       3       4       5
- More than 5

Q5.6 (1 point) At convergence, what is the next-hop toward  $A$  in R7's forwarding table?

- R2       R3       R6       None

## Q6 Longest Prefix Matching

(14 points)

IP addresses are written in binary (base-2), where every bit is either 0 or 1. In this question, we will consider writing IP addresses in *ternary* (base-3) instead, where every *trit* is either 0, 1, or 2. (A trit is the ternary equivalent of a bit.)

Q6.1 (1 point) If IPv4 addresses are 32 trits long, how many total IP addresses are available?

- $2^{32}$         $2^{35}$         $3^{32}$         $3^{35}$         $32^3$         $35^3$

Recall that classful addressing creates three types of IPv4 addresses:

Class A: 24 host bits/trits

Class B: 16 host bits/trits

Class C: 8 host bits/trits

In Q6.2 to Q6.4, create three classes of ternary 32-trit IPv4 addresses, where each class has exactly the number of host trits shown above, and as many network trits as possible.

*Hint:* Remember that some trit(s) must be used to determine which class the address belongs to.

Q6.2 (1 point) How many network trits are in a ternary Class A address?

- 5       6       7       8       9       10

Q6.3 (1 point) How many network trits are in a ternary Class B address?

- 11       12       13       14       15       16

Q6.4 (1 point) How many network trits are in a ternary Class C address?

- 20       21       22       23       24       25

For Q6.5 and Q6.6, consider classless addressing, with ternary 32-trit IPv4 addresses.

*Hint:* The powers of 3 are:

$3^0$	$3^1$	$3^2$	$3^3$	$3^4$	$3^5$	$3^6$	$3^7$	$3^8$	$3^9$	$3^{10}$
1	3	9	27	81	243	729	2187	6561	19683	59049

Q6.5 (2 points) EvanBot is given the 10.0.735.0/23 range. How many separate /27 ranges can be allocated out of this range?

- 1       3       9       27       81       729

Q6.6 (2 points) Which ranges contain the address 10.0.0.22? Select all that apply.

- 10.0.0.9/30       10.0.0.12/31       None of the above  
 10.0.0.18/30       10.0.0.21/31

(Question 6 continued...)

Q6.7 (3 points) In this subpart, we want to build a trie for longest prefix matching on ternary 32-trit IPv4 addresses.

The 9-entry forwarding table that we want to convert into a trie is shown below. Every prefix is a /2, and the two fixed bits of each prefix are provided for your convenience.

Fixed Bits	Port
00	4
01	5
02	5

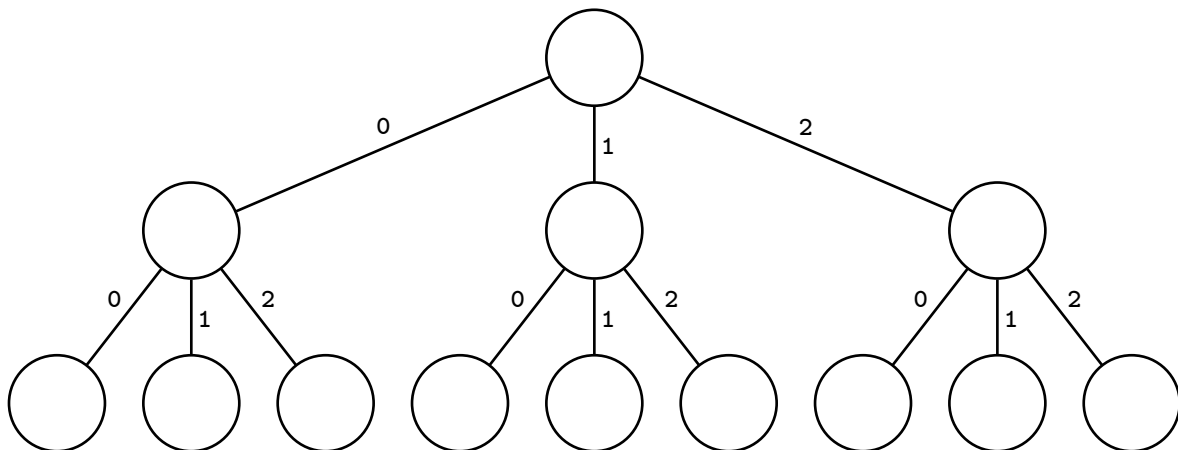
Fixed Bits	Port
10	5
11	6
12	7

Fixed Bits	Port
20	8
21	8
22	9

Fill in the trie below by writing port numbers (4, 5, ..., 9) in the circles.

Not all nodes will be used; leave unused nodes blank, and leave nodes with no label blank.

For full credit, your trie should use the minimum possible number of nodes.



In Q6.8 and Q6.9, consider a **binary** trie built for longest prefix matching on binary 32-bit IPv4 addresses:

- A default route is added in the root of the trie.
- Every non-default prefix in the trie is exactly 6 bits long (i.e. they represent /6 ranges).
- There is at least one non-default prefix, but we do not know the exact number of prefixes in the trie.

Without changing anything about the trie, we now interpret the trie as a **ternary** trie for longest prefix matching on ternary 32-trit IPv4 addresses.

Q6.8 (1 point) When interpreted as a ternary trie, what is the **minimum** number of ternary addresses that get forwarded on a non-default route?

- $3^3$      
   $3^6$      
   $2^{26}$      
   $3^{26}$      
   $2^{32}$      
   $3^{32}$

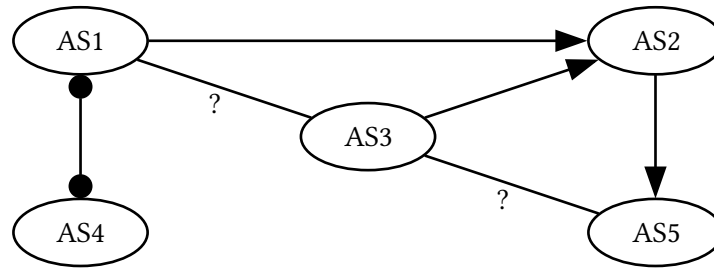
Q6.9 (2 points) When interpreted as a ternary trie, what is the **maximum** number of ternary addresses that get forwarded on a non-default route?

- $2^{26}$      
   $64 \times 2^{26}$      
   $729 \times 2^{26}$      
   $2^{32}$   
  $3^{26}$      
   $64 \times 3^{26}$      
   $729 \times 3^{26}$      
   $3^{32}$

**Q7 BGP**

**(22 points)**

Consider the AS graph below, where all ASes follow the Gao-Rexford rules.



The AS1–AS3 and AS3–AS5 relationships are unknown. In other words, the two edges marked ? could each be ●—● or → or ←.

Q7.1 (2 points) For this subpart only, suppose the AS3–AS5 edge does not exist.

How many ways are there to label AS1–AS3 edge, such that the resulting AS graph is a valid hierarchy that guarantees reachability and convergence?

- 0
  1
  2
  3

Q7.2 (3 points) How many ways are there to label the two unknown edges, such that the resulting AS graph is a valid hierarchy that guarantees reachability and convergence?

- 0
  1
  2
  3
  4
  5
  6
  7
  8
  9

Q7.3 (3 points) Which of these could be the set of Tier 1 ASes, for some labeling of the unknown edges? Select all that apply.

- AS1 only
  AS4 only
  AS1 and AS4
  None  
 AS3 only
  AS1 and AS3
  AS1, AS3, and AS4

For Q7.4 to Q7.6, select whether it is possible for packets to be sent from the source AS to the destination AS assuming a valid AS hierarchy. In other words, is there an AS path from source to destination where all intermediate ASes agree to export the path?

- “Always” means that a path exists, for any valid labeling of the unknown edges.
- “Sometimes” means that a path exists in some valid graphs and does not in others, depending on how the unknown edges are labeled.
- “Never” means that a path does not exist in any valid graph.

Q7.4 (2 points) Source: AS3, Destination: AS5

- Always
  Sometimes
  Never

Q7.5 (2 points) Source: AS4, Destination: AS3

- Always
  Sometimes
  Never

Q7.6 (2 points) Source: AS4, Destination: AS5

- Always
  Sometimes
  Never

(Question 7 continued...)

In each of Q7.7 to Q7.10, two advertisements are shown. Select the advertisement that will be imported, according to the tiebreaking priorities from lecture. If a route attribute is not shown, it could be any value.

Reminder: There could be multiple links between the same two ASes, even if the AS graph only shows one edge.

Q7.7 (2 points) If a router in AS4 hears about the two advertisements below, which one is imported?

**Advertisement I:** A router in AS1 sends: "Destination AS2 with ASPATH [AS1, AS2]."

**Advertisement II:** A different router in AS1 sends: "Destination AS2 with ASPATH [AS1, AS3, AS2]."

- Always Advertisement I.
- Always Advertisement II.
- Not enough information: Depends on the unknown edge labels.
- Not enough information: Depends on something else besides the unknown edge labels.

Q7.8 (2 points) If a router in AS2 hears about the two advertisements below, which one is imported?

**Advertisement I:** A router in AS5 sends: "Destination AS5 with ASPATH [AS5], and MED 1."

**Advertisement II:** A different router in AS5 sends: "Destination AS5 with ASPATH [AS5], and MED 2."

- Always Advertisement I.
- Always Advertisement II.
- Not enough information: Depends on the unknown edge labels.
- Not enough information: Depends on something else besides the unknown edge labels.

Q7.9 (2 points) If a router in AS3 hears about the two advertisements below, which one is imported?

**Advertisement I:** A router in AS2 sends: "Destination AS5 with ASPATH [AS2, AS5]."

**Advertisement II:** A router in AS1 sends: "Destination AS5 with ASPATH [AS1, AS2, AS5]."

- Always Advertisement I.
- Always Advertisement II.
- Not enough information: Depends on the unknown edge labels.
- Not enough information: Depends on something else besides the unknown edge labels.

Q7.10 (2 points) If a router in AS5 hears about the two advertisements below, which one is imported?

**Advertisement I:** A router in AS3 sends: "Destination AS1 with ASPATH [AS3, AS1]."

**Advertisement II:** A router in AS2 sends: "Destination AS1 with ASPATH [AS2, AS1]."

- Always Advertisement I.
- Always Advertisement II.
- Not enough information: Depends on the unknown edge labels.
- Not enough information: Depends on something else besides the unknown edge labels.

## Comment Box

Congrats for making it to the end of the exam! Leave any thoughts, comments, feedback, or doodles here. Nothing in the comment box will affect your grade.

## Ambiguities

If you feel like there was an ambiguity on the exam, you can put it in the box below.

For ambiguities, you must qualify your answer and provide an answer for both interpretations. For example, “if the question is asking about A, then my answer is X, but if the question is asking about B, then my answer is Y.” You will only receive credit if it is a genuine ambiguity and both of your answers are correct. We will only look at this box if you request a regrade.