# SE463 / CS445
## Spring/Summer 2023 — Final Exam

8 August 2023, 9:00am–11:30am
Instructor: Daniel M. Berry
Time allowed: 2.5 hours = 150 minutes
No aids allowed (*i.e.,* closed book).
Answer all of the questions on this exam paper.
There are 7 questions for a total of 150 marks.
Plan your time wisely: 1 minute per mark

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**Your Name and Student Number**

In the immortal words of the yet to be born Jean-Luc Picard of Earth,

*Make it so!*

| | | | |
|---|---|---|---|
| Q1 | | scaled to | 55 |
| Q2 | | scaled to | 25 |
| Q3 | | scaled to | 25 |
| Q4 | | scaled to | 7 |
| Q5 | | scaled to | 20 |
| Q6 | | scaled to | 10 |
| Q7 | | scaled to | 8 |
| TOTAL | | scaled to | 150 |

In this exam, if you are asked a question, which ends with a "?", you are to answer that question in the space following the current line.

In this exam, if you are asked for a simple answer, you need not justify it, unless you are also asked explicitly "Why?". However, you may always write down assumptions that can help us give you partial credit.

If an exam question directs you to list, describe, write, explain, draw, mark, put, change, modify, or anything similar, just do so.

In the exam questions,
"CBS" means "computer-based system".
"SW" means "software".
"NFR" means "non-functional requirement", a.k.a. "quality attribute".
"RE" means "requirements engineering".
"SRS" means "software requirements specification, written according to some standard, e.g., IEEE".
"UM" means "user's manual".

Note the difference between a serif font like that used for *this* clause
and a sans serif font like that used for *this* clause.
A serif font is used for ordinary text in a question, and a sans serif font is used for text in a software or requirements specification artifact.

**The last 2 pages are duplicates of text and figures in the body of the exam that you will need to consult to answer questions. You are suggested to detach these pages so that you can consult them when you need to without the hassle, annoyance, and time wastage of flipping pages.**

## SMS System

"A telephone number is a sequence of digits assigned to a landline telephone subscriber station connected to a telephone line or to a wireless electronic telephony device, such as a radio telephone or a mobile telephone, or to other devices for data transmission via the public switched telephone network (PSTN) or other public and private networks.

A telephone number serves as an address for switching telephone calls using a system of destination code routing." [https://en.wikipedia.org/wiki/Telephone_number]

Thus, a telephone number uniquely identifies a device, the target device, to which one might wish to to make a voice call or to send a text (SMS) message. This problem focuses on sending text messages.

"Short Message/Messaging Service, commonly abbreviated as SMS, is a text messaging service component of most telephone, Internet and mobile device systems. It uses standardized communication protocols that let mobile devices exchange short text messages. An intermediary service can [in some cases,] facilitate a text-to-voice conversion to be sent to landlines ... [which normally cannot receive text messages].

The [SMS] service allows users to send and receive messages of up to 160 characters (when entirely alpha-numeric) to and from GSM mobiles.

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Thus, SMS allows sending a text message of up to 160 characters to a target device via the target device's uniquely identifying telephone number. The text message itself contains no information other than the message itself, e.g., it does not have a time stamp.

Questions 1 through 2 deal with the parts of the Internet, PSTNet, and SMS network as seen by cellphones that send and receive SMS text messages. Its scope consists of Requirements R1, R2, R3 and R4:

**R1.** A cellphone that is currently powered on is able to send a text message of up to 160 characters to a target device identified by a telephone number.

**R2.** A cellphone that is currently powered on is able to receive a text message of up to 160 characters from a source device identified by a telephone number.

**R3.** A cellphone that is currently powered on, that has sent a text message to a target device receives an acknowledgment of the sent message's delivery to the target device; this acknowledgement consists of only the target device's identifying telephone number and the text message itself.

**R4.** A cellphone that is currently powered on, that has received a text message knows only the source device's identifying telephone number and the text message itself.

For clarification, note that there is no mention of time stamps, because, in fact, no time stamps are transmitted with any text messages.

The intent of R1 through R4 is to specify the behavior of simple GSM SMS text messaging as it has been for years, so that the intuition you have gained from experience with GSM SMS text messaging is valid!

1. **[55 total marks]** Domain Model, Use Cases, Domain Assumptions, and Exceptions

   (a) Complete the incomplete domain model (DM) of the SMS system, shown below by

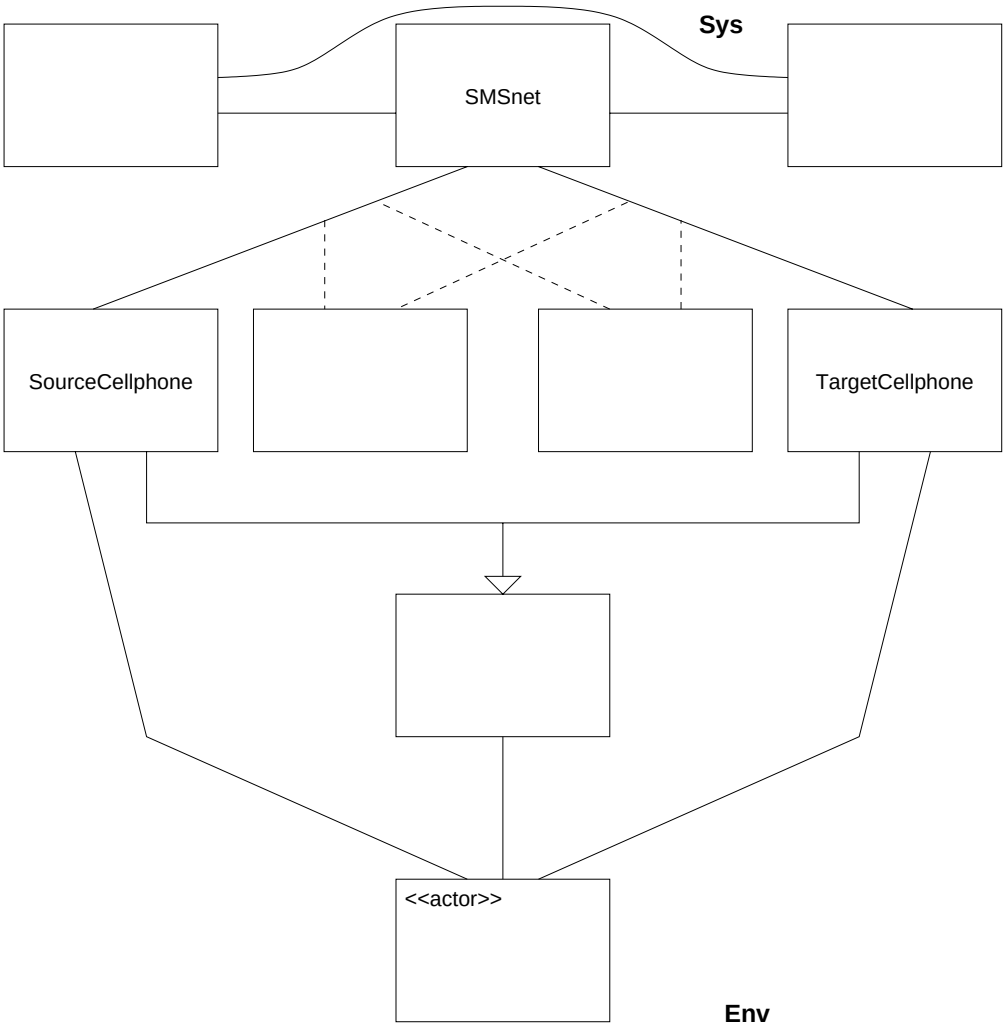
   i. putting into the correct boxes the following class names:
      - Cellphone
      - CellphoneUser
      - Internet
      - PSTNet
      - TelephoneNumber
      - TextMessage

   ii. all missing arcs between boxes,

   iii. a multiplicity in the upper right hand corner of each box,

   iv. a multiplicity at each end of each arc, except the subclassing arcs and the parameter arcs, and

   v. the boundaries of the Env and of the Sys.



(b) (1) In the first, short underscore following each user-accessible use case (UAUC), name the class whose box would contain the UAUC, and

(2) in the second, long underscore following each UAUC, name the classes that would invoke the UAUC:

(FYI: Yes, there could be more UAUCs, but the question is focusing.):

- composeTextMessage:

  container: _____

  invoker: _____

- displayTelephoneNumber:

  container: _____

  invoker: _____

- keyInTelephoneNumber:

  container: _____

  invoker: _____

- displayTextMessage:

  container: _____

  invoker: _____

- retrieveLatestReceivedTextMessage:

  container: _____

  invoker: _____

- sendComposedTextMessage:

  container: _____

  invoker: _____

- viewHistoryOfOneTargetTelephoneNumber:

  container: _____

  invoker: _____

(c) What are the parameters of the UAUC sendComposedTextMessage? For each parameter, give both (1) the parameter's object or name and (2) the parameter's class or type;

(d) What are the parameters of the UAUC viewHistoryOfOneTargetTelephoneNumber? For each parameter, give both (1) the parameter's object or name and (2) the parameter's class or type;

(e) The internal behavior of a SourceCellphone object after receiving an invocation of the UAUC sendComposedTextMessage is that the SourceCellphone object asks the SMSnet object to actually send the composed TextMessage onward towards the target device identified by the target TelephoneNumber.

Know that the target device must eventually tell the SMSnet object to send an acknowledgement that the target device has received the sent composed TextMessage, to the sending SourceCellphone object.

Therefore, what are the parameters of the internal use case (IUC) sendTextMessage? For each parameter, give both (1) the parameter's object or name and (2) the parameter's class or type.

(f) List 4 different exceptions for the UAUC sendComposedTextMessage.

(g) What domain assumption $A$ about a cellphone, *explicitly* stated in R1, R2, R3, and R4, is necessary for the behaviors described in R1, R2, R3, and R4 to happen?

(h) Can failure for $A$ to hold be mitigated by anything that a cellphone can do?

(i) If $A$ holds at the TargetCellphone of a sending of a composed TextMessage and has held since the invocation of the UAUC sendComposedTextMessage that initiated the sending of the TextMessage, according to R3, what can be said about the relationship between

(1) the actual arrival time of the TextMessage at the TargetCellphone
and
(2) the time reported in the acknowledgement of the completion of the sending reported at the SourceCellphone?

2. **[25 total marks]** G and D Requirements

Please classify each requirement below as to whether it is a G or D with reference to the scope that consists of Requirements R1, R2, R3, and R4.

(a) If the target device is shut down, then delay the transmission until the device is back on.

_____G Requirement. _____D Requirement.

(b) A text message can be an image.

_____G Requirement. _____D Requirement.

(c) If the target device is not capable of receiving text messages, don't transmit the message and inform the user.

_____G Requirement. _____D Requirement.

(d) A text message can be a file of any format.

_____G Requirement. _____D Requirement.

(e) If the phone number to which a message is being sent is not associated with any device, don't transmit the message and inform the user.

_____G Requirement. _____D Requirement.

(f) If the target device of a text message is a cellphone, use the SMS network for transmitting the text message.

_____G Requirement. _____D Requirement.

(g) If the target device of a text message is a landline phone, use the PSTN for transmitting the text message.

_____G Requirement. _____D Requirement.

(h) If the phone number to which a message is being sent is not well-formed, don't transmit the message and inform the user.

_____G Requirement. _____D Requirement.

(i) The acknowledgement of delivery of a text message shows the text message's recipient's phone number and actual arrival date and time.

_____G Requirement. _____D Requirement.

(j) Pair a cellphone being used to send and receive text messages with a computer so that the computer's message app can send and receive text messages via the cellphone, as if the computer were the cellphone; the text messages are stored in the cellphone.

_____G Requirement. _____D Requirement.

(k) An arriving text message shows the text message's sender's phone number and arrival date and time.

_____G Requirement. _____D Requirement.

(l) If both the sending cellphone and the receiving device of a text message are currently connected to the Internet, use the Internet for transmitting the text message.

_____G Requirement. _____D Requirement.

(m) An arriving text message shows the text message's sender's phone number and sending date and time.

_____G Requirement. _____D Requirement.

(n) A text message can be sent to a set of telephone numbers.

_____G Requirement. _____D Requirement.

(o) Where else in this exam booklet is a source of D requirements for the scope that consists of Requirements R1, R2, R3, and R4? Identify the place by giving its Question number and its Subquestion letter. For example, this very item is Question 2, Subquestion (o).

Question _____, Subquestion _____.

3. **[25 total marks]** Linear Temporal Logic and State Machines

Remember that
$\Box$ means "henceforth",
$\Diamond$ means "eventually",
$\bigcirc$ means "in the next state",
$\mathcal{U}$ means "until", and
$\mathcal{W}$ means "unless".
Consider the following specification written in Linear Temporal Logic:

For your information (although not really needed to do the questions),
$SN =$ *ShowingNothing*,
$S12 =$ *Showing12hrClock*,
$S24 =$ *Showing24hrClock*,
$ST =$ *ShowingTimer*,
$SL =$ *ShowingLaptime*,
$TR =$ *TimerRunning*,
$But2 =$ *Button2*, and
$But3 =$ *Button3*.

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$\Box((S12 \wedge But3) \Rightarrow \bigcirc S12)$
$\Box((S12 \wedge Mode) \Rightarrow \bigcirc ST)$
$\Box((S12 \wedge But2) \Rightarrow \bigcirc S24)$
$\Box((S12 \wedge Off) \Rightarrow \bigcirc SN)$

$\Box(S24 \Rightarrow (S24\ \mathcal{W}\ (But3 \vee Mode \vee But2 \vee Off)))$
$\Box((S24 \wedge But3) \Rightarrow \bigcirc S24)$
$\Box((S24 \wedge Mode) \Rightarrow \bigcirc ST)$
$\Box((S24 \wedge But2) \Rightarrow \bigcirc S12)$
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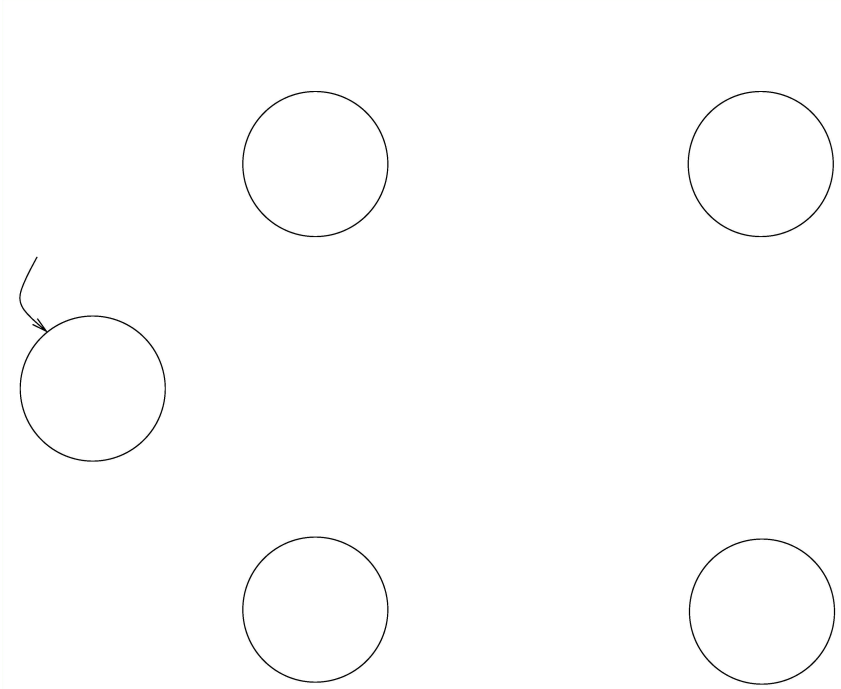
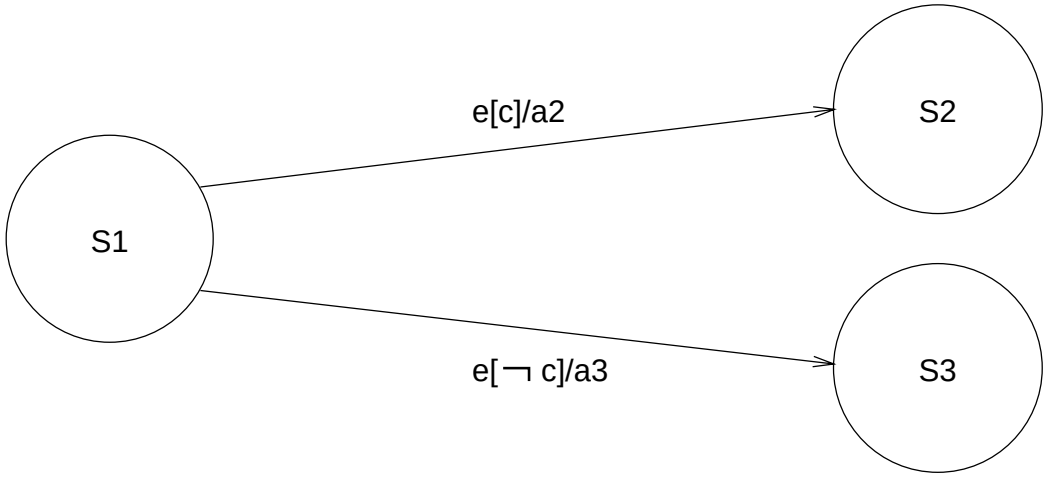
$\Box((SL \wedge Mode) \Rightarrow \bigcirc S12)$
$\Box((SL \wedge (But2 \wedge TR)) \Rightarrow \bigcirc SL)$
$\Box((SL \wedge (But2 \wedge \neg\ TR)) \Rightarrow \bigcirc SL)$
$\Box((SL \wedge Off) \Rightarrow \bigcirc SN)$

(a) Draw the specified finite state machine in the skeletal diagram below, and in this diagram, make $SN$ the initial state.



(b) Do the LTL formulae specify any state that is a final state?

(c) Express the state machine transitions




in Linear Temporal Logic. In doing so, assume:

1. There are no other events that can leave $S1$.

2. The effect of an action, $a2$ or $a3$, in any computational state is not observable until the next computational state, when the state machine is in its next state, $S2$ or $S3$. You may use a state-machine action itself as the LTL predicate describing the action's effect.

4. **[7 total marks]** Ambiguity

(a) By replacing one or more underscores with only in

_____ I _____ eat _____ eggs _____ at _____ breakfast _____.

make the sentence mean (i.e., be logically equivalent to)

I eat eggs at a meal if and only if the meal is a breakfast.

(b) We know that in sciences, a model is as good as its power to predict the outcomes in any situation. Traditionally, however, we go further and we say the sentence,

A model is only as good as its power to predict the outcomes in any situation.

to mean that a model is no better than its power to predict the outcomes in any situation.
Does the sentence say what it is intended to mean?

If not, permute the words of the sentence so the result means what the sentence is intended to mean:

(c) Liberty Mutual Insurance Company's famous advertising jingle

Only pay for what you need.

is intending to say that if you buy the company's insurance you do not have to pay for coverage that you don't need.
Does the jingle say what it is intended to say?

If not, permute the words of the jingle so the result means what the jingle is intended to say:

5. **[20 total marks]** Nonfunctional Requirements

For each nonfunctional requirement (NFR) listed below,
for each measure being used to determine if the NFR is satisfied in an implemented CBS,

- underline *all* the points of vagueness in the measure; if there are no points of vagueness, then underline the bracketed "No vagueness" that follows the measure; and
- following the prompt "Validity?", describe what might be invalid about the measure as a measure for the NFR; if the measure is valid, then write "Valid".

(a) **NFR:** The query response time is fast.
**Measure:** The response time is less than 1 second for at least 95% of the queries. [No vagueness]
**Validity?:**

(b) **NFR:** The system is reliable.
**Measure:** The mean time to failure (MTTF) of the system is at least 1 year. [No vagueness]
**Validity?:**

(c) **NFR:** The essay generated by ChatGPT is readable.
**Measure:** The Flesch Reading Ease Score (FRES) of the essay is at least 60. [No vagueness]
(For your information: The formula for the FRES of a document is
$$206.835 - 1.015(\frac{W}{S}) - 84.6(\frac{s}{W})$$
where $W$ = number of words in the document, $S$ = number of sentences in the document, and $s$ = number of syllables in the document.)
**Validity?:**

(d) **NFR:** The user interface (UI) is usable.
**Measure:** At least 75% of the users in a test of the UI say that the UI usable. [No vagueness]
**Validity?:**

(e) **NFR:** The user interface (UI) is usable.
**Measure:** At least 75% of the users in a test of the UI are able to get a correct response from the system in no more than 2 minutes. [No vagueness]
**Validity?:**

(f) **NFR:** The implementation is portable from a MSW platform to all other platforms.

**Measure:** The implementation that is ported from a MSW platform to a Linux platform passes all the regression tests. [No vagueness]

**Validity?:**

6. **[10 total marks]** Cost Estimation, Bad Bets, and ChatGPT

The reproduced 6 course-note slides given on the next page predict the total cost of writing the code of a system when the developers tried to get a head start on coding by doing two activities concurrently:

- the developers start writing the code based on requirements already understood from past developments of similar systems.
- the requirements analysts talk with the client to work out all the requirements details.

with the intention of the developers' modifying their aleady written code based on the full requirement details, when the requirements analysts finish their job.

The formula on the slide show the predicted total cost of writing the code for the system on the assumptions that

$C$ is the cost of writing the advance version and

as little as 10% of the advance version has to be modified as a result of knowing the full requirement details.

Now consider developing the *same* system with the help of ChatGPT. The *same* developers give the *same* full requirement details to ChatGPT, and ChatGPT generates some code that is not 100% correct. Then, after the *same* developers examine the code that ChatGPT generated, they determine that 10% of the code must be modified.

Your eventual assignment in the last subquestion of this question is to give a formula for the cost of modifying the ChatGPT code to match its requirements.

(a) In the formula on the last slide, the cost of developers' modifying a piece of their own code is assumed to be 10 times the original cost of writing the piece. Call this "10" the modification scaling factor (MSF). The MSF for a piece of ChatGPT-written code is the ratio:

$$\frac{\textit{the cost for human developers to modify the piece}}{\textit{the cost for human developers to develop the piece from scratch}}$$

How would you expect the MSF for humans' modifying their own code to compare to the MSF for humans' modifying ChatGPT-written code? Check the answer that you think is correct.

MSF for humans' modifying their own code $>$ MSF for humans' modifying ChatGPT-written code. _____

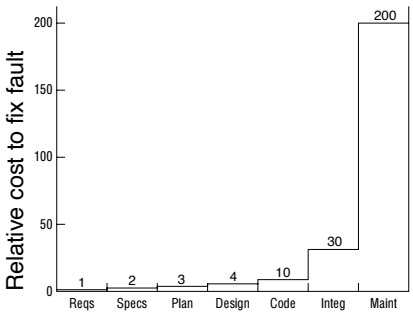
MSF for humans' modifying their own code = MSF for humans' modifying ChatGPT-written code. _____

MSF for humans' modifying their own code $<$ MSF for humans' modifying ChatGPT-written code. _____

(b) Explain your answer to Subquestion (a).

## Cost to Fix Errors

**Barry Boehm's (next slide) and Steve Schach's (slide after that) summaries of data over many application areas show that fixing an error after delivery costs two orders of magnitude more than fixing it it at requirements engineering (RE) time.**

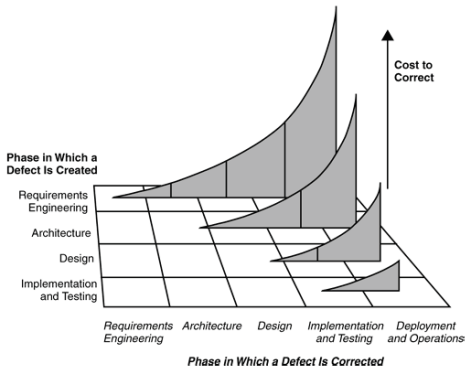



Phase in which fault is detected and fixed

## Cost to Fix Errors, Cont'd

**More specifically,**

- **requirement defects are harder to fix than architectural defects,**
- **which are harder to fix than design defects,**
- **which are harder to fix than implementation defects [Allen et al 2008].**




## Back to the Boss's Order

**If as little as 10% of the code written in advance of knowing the full requirements has to be changed after the full requirements are known, …**

**the cost of writing the code has doubled:**

## Bad Bet

**If *C* is the cost of writing the advance version, the cost of fixing the advance version when as little as 10% of it has to be changed is (10 × 0.1×*C*), and the total cost of writing the code is**

$$C + (10 \times 0.1 \times C) = 2 \times C$$

**Oy!**

**And it gets worse if more than 10% has to be changed.**

(c) Assuming that the MSF for humans' modifying ChatGPT-written code is $F$,
that the fraction of ChatGPT-written code that must be modified is $P$,
that the cost of getting ChatGPT to write its code is zero,
and that the cost for humans to write the ChatGPT-written code from scratch is $C$,
write a formula for a predicted total cost of modifying the ChatGPT-written code to match the full requirement details given to ChatGPT?

(d) Assuming that $P$ is as little as 10%, what must $F$ be in order for the value of the formula you gave in Subquestion (c) to be exactly the cost of writing the code manually from the full requirement detail?

(e) Given your answer to Subquestion (a), how would you expect the cost of humans' writing their own code from requirements to compare with the cost of humans' modifying the code that ChatGPT wrote from the same requirements? Check the answer that you think is correct.

cost for humans' writing their own code $>$ cost for humans' modifying ChatGPT-written code. _____

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7. **[8 total marks]** Internet and E-Type Systems

Recall that what is now called the Internet started off in 1969 as the ARPAnet, which was required by Kleinrock, Cerf, et al to be a completely open network, in which anyone sitting anywhere on the network was to be able to use any other site on the network as if E were sitting at the other site. In other words, the ARPAnet was required to be open and essentially insecure.

Independently, Meir Lehman described the phenomenon of an E-type system:

- An E-type system solves a problem or implements an application in some real-world domain.
- Once installed, an E-type system becomes inextricably part of the application domain, so that it ends up altering the real world in a way that alters its own requirements.

The progression from the 1969 ARPAnet to the 2021 Internet is a classic example of this phenomenon.

(a) Describe one change to the real world resulting from the introduction of the ARPA- or Internet.

(b) Describe one new, unanticipated use for ARPA- or Internet functionality that the real world discovered as a result of the change identified in your answer to (a).

(c) Describe one requirement change to the ARPA- or Internet resulting from the change identified in your answer to (b) in the way the ARPA- or Internet was used.

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