Answers to Tutorial No 5, Semester 2, 2025/2026

1. The first 11 notes of a well-known Singapore National Day song are: D4, D5, B4, C5, D5, A4, B4, A4, B4, C5 and A4. What are the MIDI key numbers for these 11 notes? Give the paper roll track numbers for the first 11 notes of this song which is to be played by a player piano using a standard player piano paper roll. How can the MIDI key numbers be converted to paper roll track numbers in general? If we start on C4 instead of D4, give the MIDI key numbers and the paper roll track numbers for these 11 notes, assuming that the notes of the song will still have the same interval relationships from the first note.

   Answer: Since the MIDI key number for C4 is 60, the MIDI key numbers for the 11 notes are: 62, 74, 71, 72, 74, 69, 71, 69, 71, 72 and 69. The paper roll track numbers for the 11 notes are: 47, 59, 56, 57, 59, 54, 56, 54, 56, 57 and 54. The MIDI key numbers can, in general, be converted to paper roll track numbers by subtracting 15 from the corresponding MIDI key numbers. Starting on C4 instead of D4, the MIDI key numbers are: 60, 72, 69, 70, 72, 67, 69, 67, 69, 70 and 67. The paper roll track numbers are 45, 57, 54, 55, 57, 52, 54, 52, 54, 55 and 52.

2. A desktop computer is able to send and receive MIDI messages through MIDI in and MIDI out sockets

through an interface box connected to the computer, and the sockets of the box are labelled IX and OX respectively. An electronic organ which has only MIDI in and MIDI out sockets labelled IR and OR respectively sends MIDI messages to the computer to enable a song to be composed on the computer. An electronic synthesiser has MIDI in, MIDI out and MIDI thru sockets labelled IS, OS and TS respectively, an electronic tone generator has MIDI in, MIDI out and MIDI thru sockets labelled IG, OG and TG respectively, and an electronic piano has MIDI in, MIDI out and MIDI thru sockets labelled IP, OP and TP respectively. The completed song is to be performed on the four electronic musical instruments (including the electronic piano). Give the connections which need to be made between the computer and the four electronic musical instruments (including the electronic organ) to enable the song to be composed and then performed as desire. If the electronic organ does have a MIDI thru socket, how would this affect the required connections?

Answer: The MIDI interface box should have its MIDI in IX connected to the MIDI out OR of the electronic organ so that MIDI messages can be sent from the electronic organ to the desktop computer, enabling the notes of the song to be input into the computer. For the completed song to be played on all four electronic musical instruments, the same MIDI messages should be sent out in sequence through OX to all the four instruments. For example, OX could be connected directly to either IS of the electronic

synthesiser, IP of the electronic piano or IG of the electronic tone generator. If OX is connected for example to IS of the electronic synthesiser, the same MIDI messages must be sent out through TS to either IP of the electronic piano or IG of the electronic tone generator. The same MIDI messages should then be sent out from the electronic piano or electronic tone generator through their MIDI thru sockets to the MIDI input of the third electronic instrument. The fourth and last instrument in the chain has to be the electronic organ as it does not have a MIDI thru socket to pass on MIDI messages. If the electronic organ did have a MIDI thru socket, it would be possible for it to pass on MIDI messages, and therefore the four electronic musical instruments can be connected to the MIDI output of the MIDI interface box in any order.

3. The first 11 notes of the National Day song in question 1 are sent to an electronic synthesiser by a series of MIDI messages. The song is to be played on the trumpet MIDI instrument in the lowest MIDI channel by turning the notes on and off as fast as possible starting from the note D4. What are the MIDI messages which should be sent?
   Answer: The number in the first message is the number 12 for a MIDI program change; the second number is 0 for the lowest MIDI channel, and the third number is 56 for the trumpet in the GM set. For each note of the song, two MIDI messages should be sent : the first message starting with a 9 to turn

the note on, and the second starting with an 8 to turn the note off. The MIDI message in decimal number sequence for the 11 notes of the song is thus as follows:
9, 0, 62, 127;
8, 0, 62, 127;
9, 0, 74, 127;
8, 0, 74, 127;
9, 0, 71, 127;
8, 0, 71, 127;
9, 0, 72, 127;
8, 0, 72, 127;
9, 0, 74, 127;
8, 0, 74, 127;
9, 0, 69, 127;
8, 0, 69, 127;
9, 0, 71, 127;
8, 0, 71, 127;
9, 0, 69, 127;
8, 0, 69. 127;
9, 0, 71, 127;
8, 0, 71, 127;
9, 0, 72, 127;
8, 0, 72, 127;
9, 0, 69, 127; and
8, 0, 69, 127.

4. 15 electronic keyboards are connected by MIDI cables to a notebook computer to enable all the keyboards to play a piece of music together. One partic-

ular chord in this piece is to be played simultaneously by all the 15 electronic keyboards, with all the 15 keyboards playing the same number of notes of this chord. If all the notes of the chord have to be played within 0.08 seconds, what is the maximum number of notes which this chord can have? If the time duration is 0.13 seconds instead of 0.08 seconds, what is the maximum number of notes which the chord can have? (Assume that it takes exactly one millisecond for a MIDI message to go through the MIDI sockets of all the 15 electronic keyboards.)

Answer: If a single MIDI message takes exactly one millisecond to reach all the 15 electronic keyboards, within 0.08 seconds or 80 milliseconds, only 80 MIDI messages can be sent from the notebook computer to all the 15 electronic keyboards. The MIDI messages are to be sent one after another and not simultaneously, and one MIDI message is required to turn on each note in the chord. Therefore the total number of notes which each electronic keyboard can play is given by 80 notes divided by 15 i.e. approximately 5.33 notes. The number of notes played by each keyboard has to be an integer, so each electronic keyboard can only play 5 notes, and hence the chord can have at most 5 notes times 15 keyboards i.e. 75 notes. If the time duration is 0.13 seconds or 130 milliseconds instead of 80 milliseconds, the number of notes each electronic keyboard can play is equal to 130 notes divided by 15 keyboards i.e. approximately 8.67 notes. Therefore each electronic keyboard will thus be able to play 8 notes, making the

total number of notes in the chord equal to 8 notes times 15 i.e. 120 notes.

5. The Nyquist theorem says that the sampling rate of a digital recording or transmission should be double the highest frequency to be preserved in the recording or transmission. If, for example, the highest frequency to be preserved is f Hz, the sampling rate should be $2f$ samples per second. A Chinese orchestra concert is being digitally recorded with the highest frequency to be preserved being 17,400 Hz. What is the bit rate of the recording if the bit length of the digital samples in the digital recording is 14 bits? If the highest frequency to be preserved is 20,600 Hz instead, calculate the maximum possible bit length of the digital samples for the same bit rate. (Assume that the digital recording is in stereo, with two audio channels of equal bit rates to be digitally recorded.)
Answer: Since the highest frequency to be preserved in the digital recording of the Chinese orchestra concert is 17,400 Hz, by the Nyquist theorem, the sampling frequency should be double this frequency i.e. 34,800 samples per second. Therefore each of the two stereo audio channels has a bit rate of 34,800 samples per second times 14 bits i.e. 487,200 bits per second, and for two audio channels the bit rate is twice this i.e. 974,400 bits per second. If the highest frequency to be preserved is 20,600 Hz instead of 17,400 Hz, the Nyquist sampling rate would now be double 20,600 Hz i.e. 41,200 samples per second. If we assume that the bit rate is still 974,400 bits

per second for two audio channels, for each channel the bit length of the digital samples will be equal to 487,200 bits per second divided by 41,200 samples per second, i.e. approximately 11.83 bits. Since bit length has to be an integer, the bit length is 11 bits, because for a bit length of 12 bits, the bit rate would be 494,400 bits per second which would exceed the allowable maximum bit rate per channel of 487,200 bits per second.

Scientific Inquiry discussion points

(a) The invention of sound recording by Edison and others, and of radio transmission later, made it possible for music to be recorded and heard by many more listeners than hitherto. This was multiplied greatly and the fidelity of the recordings vastly improved when digital transmission and recording, coupled with smartphones and the Internet, made both live and recorded music easily accessible to a large proportion of the world's population. Hence the societal impact of science and technology can indeed be immense. Can you cite other scientific and technological innovations which had a similar or greater impact on society?

The invention of the telegraph around 1840 was one of the most significant technological innovations in the history of human society. Prior to the telegraph, communicating a message had to be done through physical means, such as through messengers on horseback, or by using visible signals such as bright lamps or smoke signals. This

meant that messages over hundreds or thousands of miles needed many hours or even days for transmission. The telegraph, which communicated messages over electrical wires, dramatically shortened the time needed to a matter of minutes. Only an "off-on" signal could be transmitted, so a code - the Morse code - was devised by Samuel Morse, one of the telegraph's principal inventors, to transmit numbers and the letters of the alphabet. Another innovation which had a similarly huge impact on society was the invention of the steam engine by Newcomen, Watt and others. The steam engine freed society from the constraints of human muscle power and the wind or water currents. Steamships made sea travel faster, safer and more reliable. Railway travel powered by steam locomotives dramatically shrunk travel times first in England and then in the rest of the World. Steam power also enabled and drove the Industrial Revolution which profoundly transformed human society.