Answers to Tutorial No 5, Semester 1, 2026/2027

1. The first 10 notes of a well-known Singapore song are: C4, F4, G4, A4, A4, A4, G4, F4, E4 and F4. Give the MIDI key numbers for these 10 notes. What are the paper roll track numbers for the first 10 notes of this song for it to be played by a player piano using a standard player piano paper roll? Show how the MIDI key numbers can be converted to paper roll track numbers in general. If we start on D4 instead of C4, what would be the MIDI key numbers and the paper roll track numbers for these 10 notes, assuming that the notes of the song will still have the same interval relationships from the first note?
   Answer: The MIDI key number for C4 is 60, so the MIDI key numbers for the 10 notes are: 60, 65, 67, 69, 69, 69, 67, 65, 64 and 65. The paper roll track numbers for the 10 notes are: 45, 50, 52, 54, 54, 54, 52, 50, 49 and 50. In general, the MIDI key numbers can be converted to their paper roll track number equivalents by subtracting 15 from the corresponding MIDI key numbers. If we start on D4 instead of C4, the MIDI key numbers are: 62, 67, 69, 71, 71, 71, 69, 67, 66 and 67. The paper roll track numbers are 47, 52, 54, 56, 56, 56, 54, 52, 51 and 52.

2. A notebook computer can send and receive MIDI messages through MIDI in and MIDI out sockets through an interface box connected to the computer.

The sockets of the box are labelled IB and OB respectively. An electronic piano which has only MIDI in and MIDI out sockets labelled IP and OP respectively is able to send MIDI messages to the computer for a song to be composed on the computer. An electronic organ has MIDI in, MIDI out and MIDI thru sockets labelled IR, OR and TR respectively, an electronic synthesiser has MIDI in, MIDI out and MIDI thru sockets labelled IS, OS and TS respectively, and an electronic tone generator has MIDI in, MIDI out and MIDI thru sockets labelled IG, OG and TG respectively. When the song is completed, it is to be performed on the four electronic musical instruments (including the electronic piano). What are the connections which need to be made between the computer and the four electronic musical instruments (including the electronic piano) to enable the song to be composed and then performed as desired? If the electronic piano does have a MIDI thru socket, how would this affect the required connections?

Answer: The MIDI in IB of the MIDI interface box should be connected to the MIDI out OP of the electronic piano so that MIDI messages can be sent from the electronic piano to the notebook computer to enable the notes of the song to be input into the computer. To enable the completed song to be played on all four electronic musical instruments, the same MIDI messages should be sent out in sequence through OB to all the four instruments. For example, OB could be connected directly to either IR of the electronic organ, IS of the electronic synthesiser

or IG of the electronic tone generator. For example, if OB is connected to IR of the electronic organ, the same MIDI messages should be sent out through TR to either IS of the electronic synthesiser or IG of the electronic tone generator. The same MIDI messages should then be sent out from the electronic synthesiser or electronic tone generator through their MIDI thru sockets to the MIDI input of the third electronic instrument. Since it does not have a MIDI thru socket to pass on MIDI messages, the fourth and last instrument in the chain must be the electronic piano. If the electronic piano did have a MIDI thru socket, it could then pass on MIDI messages, and hence the four electronic musical instruments can be connected to the MIDI output of the MIDI interface box in any order.

3. The first 10 notes of the song in question 1 are to be sent to an electronic organ by a series of MIDI messages. The song is to be played on the clarinet 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 should be the number 12 for a MIDI program change; the second number should be 0 for the lowest MIDI channel, and the third number is 71 for the clarinet in the General MIDI set. For each note of the song, two MIDI messages have to be sent : the first message starts 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 10 notes of the song is thus as follows:
9, 0, 62, 127;
8, 0, 62, 127;
9, 0, 67, 127;
8, 0, 67, 127;
9, 0, 69, 127;
8, 0, 69, 127;
9, 0, 71, 127;
8, 0, 71, 127;
9, 0, 71, 127;
8, 0, 71, 127;
9, 0, 71, 127;
8, 0, 71, 127;
9, 0, 69, 127;
8, 0, 69, 127;
9, 0, 67, 127;
8, 0, 67. 127;
9, 0, 66, 127;
8, 0, 66, 127;
9, 0, 67, 127; and
8, 0, 67, 127.

4. 12 electronic pianos are connected by MIDI cables to a desktop computer so that all the pianos can play a piece of music together. A certain chord in this piece is to be played simultaneously by all the 12 electronic pianos, and all the 12 pianos play the same number of notes of this chord. If all the notes

of the chord have to be played within 0.11 seconds, calculate the maximum number of notes which this chord can have. If the time duration is 0.09 seconds instead of 0.11 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 12 electronic pianos.)

Answer: One MIDI message takes exactly one millisecond to reach all the 12 electronic keyboards, so within 0.11 seconds or 110 milliseconds, only 110 MIDI messages can be sent from the notebook computer to all the 12 electronic pianos. Since the MIDI messages are sent one after another and not simultaneously, and one MIDI message is required to turn on each note in the chord, the total number of notes which each electronic keyboard can play is given by 110 notes divided by 12 i.e. approximately 9.167 notes. However, the number of notes played by each electronic piano must be an integer, so each electronic piano can only play 9 notes. Therefore the chord can have at most 9 notes times 12 keyboards i.e. 108 notes. If the time duration is 0.09 seconds or 90 milliseconds instead of 110 milliseconds, the number of notes each electronic piano can play is given by 90 notes divided by 12 keyboards i.e. 7.5 notes. Hence each electronic piano will be able to play only 7 notes, so the total number of notes in the chord is equal to 7 notes times 12 i.e. 84 notes.

5. According to the Nyquist theorem, the sampling rate

of a digital recording or transmission should be double the highest frequency to be preserved in the recording or transmission. For example, if the highest frequency to be preserved is f Hz, the sampling rate should be $2f$ samples per second. The highest frequency to be preserved in the recording of a chamber music concert is 18,600 Hz. Calculate the bit rate of the recording if the bit length of the digital samples in the digital recording is 15 bits. If the highest frequency to be preserved is 21,300 Hz instead, what is 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: The highest frequency to be preserved in the digital recording of the chamber music concert is 18,600 Hz, so by the Nyquist theorem the sampling frequency should be double this frequency i.e. 37,200 samples per second. Each of the two stereo audio channels thus has a bit rate of 37,200 samples per second times 15 bits i.e. 558,000 bits per second. For two audio channels the bit rate is twice this i.e. 1,116,000 bits per second. If the highest frequency to be preserved is 21,300 Hz instead of 18,600 Hz, the Nyquist sampling rate would now be double 21,300 Hz i.e. 42,600 samples per second. Assuming that the bit rate is still 1,116,000 bits per second for two audio channels, for each channel the bit length of the digital samples will be given by 558,000 bits per second divided by 42,600 samples per second, i.e. approximately 13.1 bits. However, bit length must

an integer so the bit length is 13 bits. A bit length of 14 bits would give a bit rate of 596,400 bits per second which would exceed the allowable maximum bit rate per channel of 558,000 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.