Answers to Tutorial No 5, Semester 1, 2025/2026

1. The first 16 notes of a well-known Singapore National Day song are: F4, E4, D4, D4, C4, C4, D4, E4, F4, E4, D4, D4, C4, C4, E4 and G4. Give the MIDI key numbers for these 16 notes, as well as the paper roll track numbers for the first 16 notes of this song which is to be played by a player piano using a standard player piano paper roll. Show how in general, the MIDI key numbers can be converted to paper roll track numbers. If we start on A4 instead of F4, what would be the MIDI key numbers and the paper roll track numbers for these 16 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 16 notes are: 65, 64, 62, 62, 60, 60, 62, 64, 65, 64, 62, 62, 60, 60, 64, and 67. The paper roll track numbers for the 16 notes are: 50, 49, 47, 47, 45, 45, 47, 49, 50, 49, 47, 47, 45, 45, 49 and 52. 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 A4 instead of F4, the MIDI key numbers are: 69, 68, 66, 66, 64, 64, 66, 68, 69, 68, 66, 66, 64, 64, 68, and 71. The paper roll track numbers are 54, 53, 51, 51, 49, 49, 51, 53, 54, 53, 51, 51, 49, 49, 53 and 56.

2. A notebook computer is enabled to send and receive MIDI messages through MIDI in and MIDI out sockets on an interface box connected to the computer, the sockets being labelled IB and OB respectively. MIDI messages are sent by an electronic piano, which has only MIDI in and MIDI out sockets labelled IP and OP respectively, to the computer enabling 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 keyboard has MIDI in, MIDI out and MIDI thru sockets labelled IK, OK and TK respectively, and an electronic tone generator has MIDI in, MIDI out and MIDI thru sockets labelled IG, OG and TG respectively. If the completed song 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 does this affect the required connections?

   Answer: The MIDI interface box should have its MIDI in IB 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 play the completed song on all four electronic musical instruments, the same MIDI messages should be sent out through OB to all the four

instruments in sequence. For example, OB may be connected directly to either IR of the electronic organ, IK of the electronic keyboard 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 IK of the electronic keyboard or IG of the electronic tone generator. The same MIDI messages should then be sent out from the electronic keyboard or electronic tone generator through their MIDI thru sockets to the MIDI input of the third electronic instrument. The electronic piano must be the fourth and last instrument in the chain as it does not have a MIDI thru socket to pass on MIDI messages. If the electronic piano does have a MIDI thru socket, it would be able to pass on MIDI messages, and hence the four electronic musical instruments may be connected to the MIDI output of the MIDI interface box in any order.

3. An electronic keyboard is to receive MIDI messages to play the first 16 notes of the National Day song in question 1 on the flute MIDI instrument in the lowest MIDI channel, turning the notes on and off as fast as possible, and starting from the note G4. 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 73 for the flute 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. Therefore the MIDI message decimal number sequence for the 16 notes of the song is as follows:
9, 0, 67, 127;
8, 0, 67, 127;
9, 0, 66, 127;
8, 0, 66, 127;
9, 0, 64, 127;
8, 0, 64, 127;
9, 0, 64, 127;
8, 0, 64, 127;
9, 0, 62, 127;
8, 0, 62, 127;
9, 0, 62, 127;
8, 0, 62, 127;
9, 0, 64, 127;
8, 0, 64, 127;
9, 0, 66, 127;
8, 0, 66, 127;
9, 0, 67, 127;
8, 0, 67, 127;
9, 0, 66, 127;
8, 0, 66, 127;
9, 0, 64, 127;
8, 0, 64, 127;
9, 0, 64, 127;
8, 0, 64, 127;
9, 0, 62, 127;
8, 0, 62, 127;
9, 0, 62, 127;

8, 0, 62, 127;
9, 0, 66, 127;
8, 0, 66, 127;
9, 0, 69, 127; and
8, 0, 69, 127.

4. MIDI cables connect 14 electronic organs to a desktop computer to enable all the organs to play a piece of music together. A particular chord in this piece is to be played simultaneously by all the 14 electronic organs. If all the 14 organs play the same number of notes of this chord, and all the notes of the chord have to be played within 0.12 seconds, calculate the maximum number of notes which this chord can have. If the time duration is 0.15 seconds instead of 0.12 seconds, calculate 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 14 electronic organs.)

   Answer: The MIDI messages are to be sent one after another and not simultaneously. So if a single MIDI message takes exactly one millisecond to reach all the 14 electronic organs, within 0.12 seconds or 120 milliseconds, only 120 MIDI messages can be sent from the desktop computer to all the 14 electronic organs. One MIDI message is required to turn on each note in the chord, so the total number of notes which each electronic organ can play equals 120 notes divided by 14 i.e. approximately

8.57 notes. However, the number of notes played by each organ has to be an integer, so each electronic organ can only play 8 notes. Hence the chord can have at most 8 notes times 14 organs i.e. 112 notes. If the time duration is 0.15 seconds or 150 milliseconds instead of 120 milliseconds, the number of notes each electronic organ can play is equal to 150 notes divided by 14 organs i.e. approximately 10.71 notes. Each electronic piano will thus be able to play 10 notes, making the total number of notes in the chord equal to 10 notes times 14 i.e. 140 notes.

5. According to the Nyquist theorem, the sampling rate of a digital recording or transmission is 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 must be $2f$ samples per second. If a symphony orchestra concert is being digitally recorded with the highest frequency to be preserved being 19,800 Hz, calculate the bit rate of the recording if the bit length of the digital samples in the digital recording is 15 bits. If we change the highest frequency to be preserved to 17,200 Hz, what would be 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 symphony orchestra concert is 19,800 Hz, so by the Nyquist theorem, the

sampling frequency should be double this frequency i.e. 39,600 samples per second. Thus each of the two stereo audio channels has a bit rate of 39,600 samples per second times 15 bits i.e. 594,000 bits per second, and for two audio channels the bit rate is twice this i.e. 1,188,000 bits per second. If the highest frequency to be preserved is changed to 17,200 Hz instead of 19,800 Hz, the Nyquist sampling rate would now be double 17,200 Hz i.e. 34,400 samples per second. If we assume that the bit rate is still 1,188,00 bits per second for two audio channels, for each channel the bit length of the digital samples will be equal to 594,000 bits per second divided by 34,400 samples per second, i.e. approximately 17.27 bits. Since bit length has to be an integer, the bit length is 17 bits, because for a bit length of 18 bits, the bit rate would be 619,200 bits per second which exceeds the allowable maximum bit rate per channel of 594,000 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.