# Answers to Tutorial No 5, Semester 1, 2024/2025

1. The first 11 notes of the chorus of a popular Singapore National Day song are: C4, C5, A4, Bflat4, C5, G4, Bflat4, A4, Bflat4, C5 and G4. 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 are the MIDI key numbers converted to paper roll track numbers in general. If we start on F4 instead of C4, what would be 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 with the first note?
   **Answer:** Since the MIDI key number for C4 is 60, the MIDI key numbers for the 11 notes are: 60, 72, 69, 70, 72, 67, 70, 69, 70, 72, and 67. The paper roll track numbers for the 11 notes are: 45, 57, 54, 55, 57, 52, 55, 54, 55, ni 57 and 52. In general, the MIDI key numbers can be converted to paper roll track numbers by subtracting 15 from the corresponding MIDI key numbers. If we start on F4 instead of C4, the MIDI key numbers are: 65, 77, 74, 75, 77, 72, 75, 74, 75, 77 and 72, and the paper roll track numbers are 50, 62, 59, 60, 62, 57, 60, 59, 60, 62 and 57.

2. A notebook computer is connected to a MIDI interface box, enabling the computer to send and re-

ceive MIDI messages through MIDI in and MIDI out sockets on the interface box which are labelled IX and OX respectively. An electronic keyboard which has only MIDI in and MIDI out sockets labelled IK and OK respectively sends MIDI messages to the computer enabling a song to be composed on the computer. An electronic piano has MIDI in, MIDI out and MIDI thru sockets labelled IP, OP and TP respectively, an electronic tone generator has MIDI in, MIDI out and MIDI thru sockets labelled IG, OG and TG respectively, and an electronic organ has MIDI in, MIDI out and MIDI thru sockets labelled IR, OR and TR respectively. The completed song is to be performed on the four electronic musical instruments (including the electronic keyboard). Give the connections which need to be made between the computer and the four electronic musical instruments (including the electronic keyboard) to enable the song to be composed and then performed as desired. If the electronic keyboard has a MIDI thru socket, how are the required connections affected?

**Answer:** The electronic keyboard should have its MIDI out OK connected to the MIDI in IX of the MIDI interface box so that MIDI messages can be sent from the electronic keyboard to the notebook computer. To enable the completed song to be performed on all four electronic musical instruments, the same MIDI messages should be sent out through OX to all the four instruments in sequence. For example, OX may be connected directly to either IP of the electronic piano, IG of the electronic tone genera-

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

3. MIDI messages are to be sent to a synthesizer to play the first 11 notes of the National Day song in question 1 on the clarinet MIDI instrument in the highest MIDI channel, turning the notes on and off as fast as possible, and starting from the note C4. What are the MIDI messages which should be sent?
**Answer:** The first message has the number 12 for a MIDI program change; the second number is 15 for the highest MIDI channel, and the third number is 71 for the clarinet in the GM set. Two MIDI messages should be sent for each note of the song: the first message should start with a 9 to turn the note on, and the second should start with an 8 to turn the note off. The MIDI message decimal number se-

quence for the 11 notes of the song is thus as follows:
9, 15, 60, 127;
8, 15, 60, 127;
9, 15, 72, 127;
8, 15, 72, 127;
9, 15, 69, 127;
8, 15, 69, 127;
9, 15, 70, 127;
8, 15, 70, 127;
9, 15, 72, 127;
8, 15, 72, 127;
9, 15, 67, 127;
8, 15, 67, 127;
9, 15, 70, 127;
8, 15, 70, 127;
9, 15, 69, 127;
8, 15, 69, 127;
9, 15, 70, 127;
8, 15, 70, 127;
9, 15, 72, 127;
8, 15, 72, 127;
9, 15, 67, 127;
8, 15, 67, 127;

4. 13 electronic pianos are connected through MIDI cables to a notebook computer to enable all the pianos to play a piece of music together, and a certain chord in this piece is to be played simultaneously by all the 13 electronic pianos. Assuming that all the 13 pianos play the same number of notes of this chord, and

also that all the notes of the chord have to be played within 0.14 seconds, what is the maximum number of notes which this chord can have? If the time duration is 0.11 seconds instead of 0.14 seconds, what is the maximum number of notes that 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:** Since the MIDI messages are to be sent one after another and not simultaneously, assuming that a single MIDI message takes exactly one millisecond to reach all the 13 electronic pianos, within 0.14 seconds or 140 milliseconds, only 140 MIDI messages can be sent from the desktop computer to all the 13 electronic pianos. Since one MIDI message is needed to turn on each note in the chord, the total number of notes which each electronic piano can play is given by 140 notes divided by 13 i.e. approximately 10.77 notes. The number of notes played by each piano must be an integer, which means that each electronic piano can only play 10 notes so the chord can have no more than 10 notes times 13 pianos i.e. 130 notes. For a time duration of 0.1 seconds or 110 milliseconds instead of 140 milliseconds, the number of notes each electronic piano can play is given by 110 notes divided by.e. approximately 8.46 notes. Therefore each electronic piano will be able to play only 8 notes, so the total number of notes in the chord is given by 8 notes times 13 i.e. 104 notes.

5. The sampling rate of a digital recording or transmis-

sion is double the highest frequency to be preserved in the recording or transmission, according to the Nyquist theorem. If, for example, the highest frequency to be preserved is $f$ Hz, the sampling rate should be $2f$ samples per second. A jazz concert is being digitally recorded with the highest frequency to be preserved being 18,200 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 changed to to 16,600 Hz, 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:** By the Nyquist theorem, since the highest frequency to be preserved in the digital recording of the jazz concert is 18,200 Hz, the sampling frequency is double this frequency i.e. 36,400 samples per second. Each of the two stereo audio channels thus has a bit rate of 36,400 samples per second times 14 bits i.e. 509,600 bits per second, and for two audio channels the bit rate is twice this i.e. 1,019,200 bits per second. If the highest frequency to be preserved is changed to 16,600 Hz instead of 18,200 Hz, the Nyquist sampling rate would now be double 16,600 Hz i.e. 33,200 samples per second. Assuming that the bit rate is still 1,019,200 bits per second for two audio channels, for each channel the bit length of the digital samples will be equal to 509,600 bits per second divided by 33,200 samples per second, i.e. ap-

proximately 15.35 bits. However, bit length should be an integer, so the bit length is 15 bits. For a bit length of 16 bits, the bit rate would be 531,200 bits per second, greater than the allowable maximum bit rate per channel of 509,600 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.*