Minimum Concurrency for Assembling Computer Music

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Roadmap

Motivation

- The *Dining Philosophers:* proposed by *Edsger Dijkstra* in 1965 to illustrate *deadlocks, starvation* and race condition.
- Variant with two states: "eating" (consuming resources) or "hungry" (ready to eat).

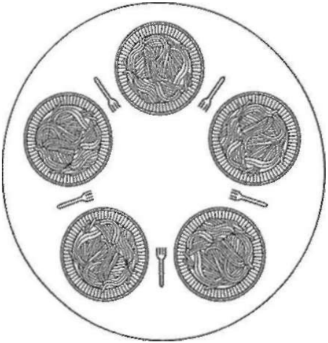


Figure 1:
The *Dining Philosophers* [1].

Resource Graph

- Nodes represent processes to be scheduled.
- Edges represent shared resources between two nodes.
- How to schedule nodes in order to attain justice and prevent classic scheduling problems?

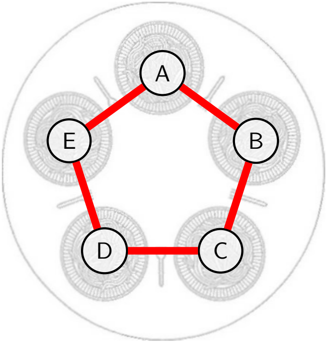


Figure 2: Resource Graph for the *Dining Philosophers*.

Scheduling by Edge Reversal *(SER)*

- Distributed solution for heavily loaded neighborhood-constrained systems.
- Acyclic orientation: *sinks* operate simultaneously and revert their edges, forming new *sinks*.
- Justice: all nodes operate the same number of times within a period.

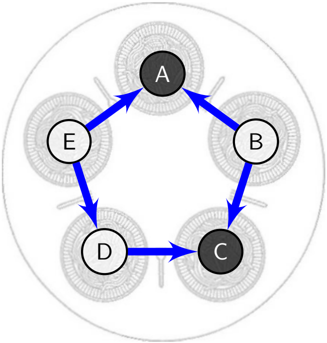
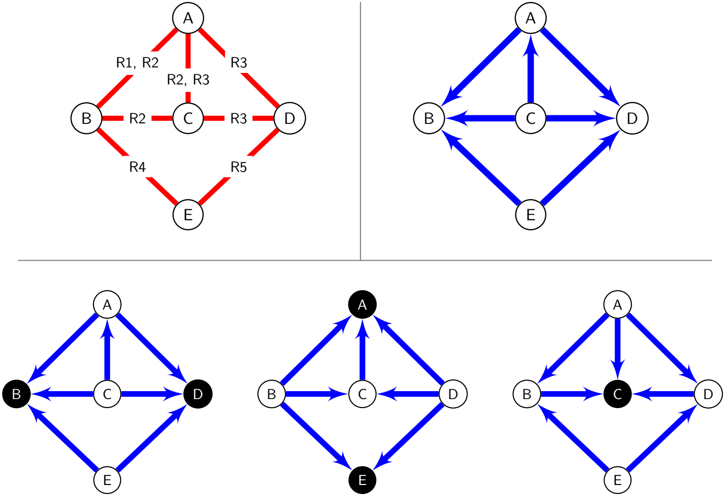
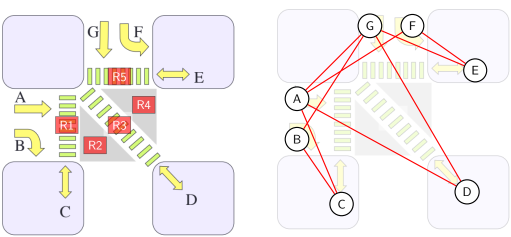


Figure 3: *DAG* representing the *Dining Philosophers.*

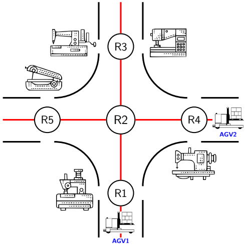
SER Example



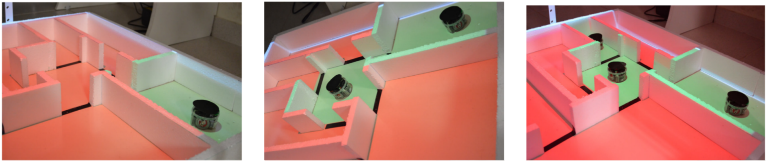
Applications



(d) Road junctions [2].



(e) AGV Routing [3].



(f) Firefighting by autonomous robots [4].

Figure 4: *SER* applications.

Definitions

Simple Cycle

Acyclic Orientation

Direction of Orientation

$$n_{cw}(\kappa, \omega) = 3$$
$$n_{ccw}(\kappa, \omega) = 1$$

Definitions

Simple Cycle

$\dots$

$\kappa_3 = \{i_0, \dots, i_{|\kappa_3 - 1|}, i_0\}$

$\kappa_1 = \{i_0, \dots, i_{|\kappa_1 - 1|}, i_0\}$

$\kappa_2 = \{i_0, \dots, i_{|\kappa_2 - 1|}, i_0\}$

$\dots$

K

Acyclic Orientation

$\dots$

$\omega_3 : E \to V$

$\omega_1 : E \to V$

$\omega_2 : E \to V$

$\dots$

Ω

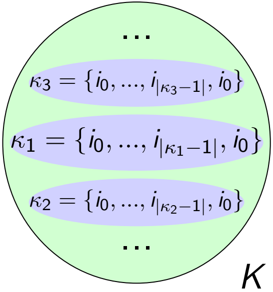
Direction of Orientation

$n_{cw}(\kappa, \omega) = 3$

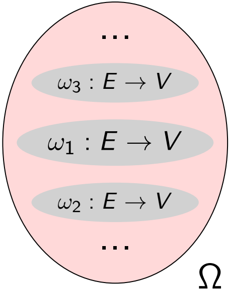
$n_{ccw}(\kappa, \omega) = 1$

Definitions

Simple Cycle



Acyclic Orientation



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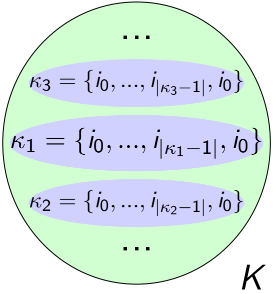
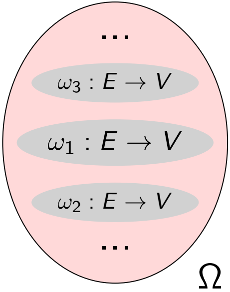
Definitions

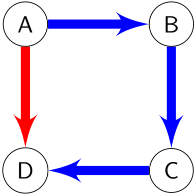
Simple Cycle



Acyclic Orientation



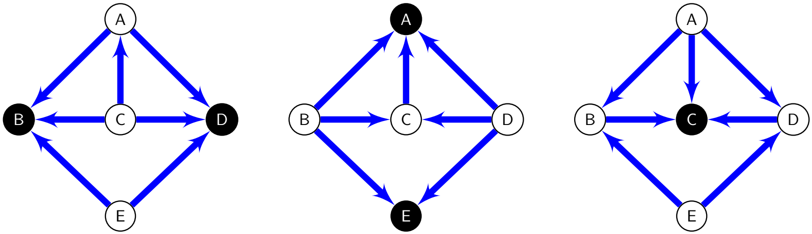
Direction of Orientation



$$n_{cw}(\kappa, \omega) = 3$$
$$n_{ccw}(\kappa, \omega) = 1$$

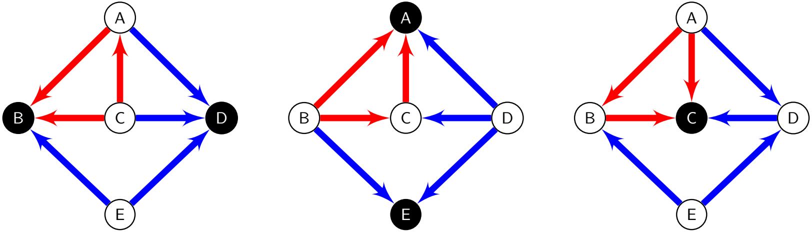
SER Concurrency ($\gamma : \Omega \to \mathbb{R}$), dynamic definition

$$\gamma(\omega) = \frac{\#\ of\ times\ each\ node\ operates}{period\ length}$$



SER Concurrency ($\gamma : \Omega \rightarrow \mathbb{R}$), static definition

$$\gamma(\omega) = \min_{\kappa \in K} \left\{ \frac{min\left\{n_{cw}(\kappa,\omega), n_{ccw}(\kappa,\omega)\right\}}{|\kappa|} \right\}$$



Roadmap

Minimum Concurrency via Maximum Cycles

$$\gamma(\omega) = \min_{\kappa \in K} \left\{ \frac{min\left\{n_{cw}(\kappa,\omega), n_{ccw}(\kappa,\omega)\right\}}{|\kappa|} \right\}$$

Minimum Concurrency via Maximum Cycles

- NP-Complete [5]: Minimize $\gamma(\omega)$ over all $\omega \in \Omega$:

$$\gamma^* = \min_{\omega \in \Omega} \left\{ \min_{\kappa \in K} \left\{ \frac{\min \{n_{cw}(\kappa,\omega), n_{ccw}(\kappa,\omega)\}}{|\kappa|} \right\} \right\}$$

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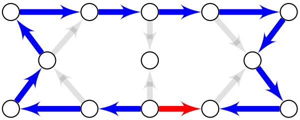


Minimum Concurrency via Maximum Cycles

- NP-Complete [5]: Minimize $\gamma(\omega)$ over all $\omega \in \Omega$:

$$\gamma^* = \min_{\omega\in\Omega}\left\{\min_{\kappa\in K}\left\{\frac{\min\{n_{cw}(\kappa,\omega), n_{ccw}(\kappa,\omega)\}}{|\kappa|}\right\}\right\}$$

Lemma 1

$$\gamma^* = \min_{\kappa\in K}\left\{\frac{1}{|\kappa|}\right\}$$

Concorrência Mínima via Ciclos Máximos (2)

- We still need to find ω^* such that $\gamma(\omega^*) = \gamma^*$:

Algorithm 1: Obtaining an orientation in linear time that leads to minimum concurrency.

Input : Undirected graph $G = (V, E)$ and longest cycle $\kappa^* \subseteq V$

- Assign increasing ids to each vertex of κ^*
- Assign increasing ids (strictly greater than the ones in κ^*) to remaining vertices
- Create an "empty" orientation ω^*
- Orient edges towards the smaller (or larger) ids

return ω^*

Experimental Results

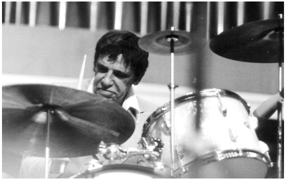
- *Simple Cycle Problem* model from Lucena et al. [6]:

Nodes	p	Avg. Edges	Solved	Avg. Min. Conc.	CPU Time (s)
200	0.01	391	10	1/178	0.6 (± 0.9)
200	0.1	3 780	10	1/200	6.5 (± 7.3)
1000	0.002	2 062	10	1/905	73.2 (± 51.4)
1000	0.02	19 695	10	1/1000	797.0 (± 547.3)
1000	0.2	179 806	3	1/1000	2 619.9 (± 1 015.0)
2000	0.001	4 091	10	1/1805	425.9 (± 371.3)
2000	0.01	39 807	3	1/2000	2 107.9 (± 1 561.5)
2000	0.1	380 199	0	–	–

Table 1: Experiments for finding minimum concurrency of random graphs G(n,p).

Roadmap

Musical Context



(j) Buddy Rich, jazz.

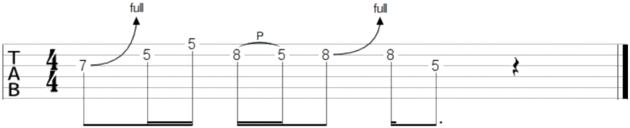
(k) Joe Bonamassa, blues.

Figure 5: Virtuosos *(Creative Commons)*.

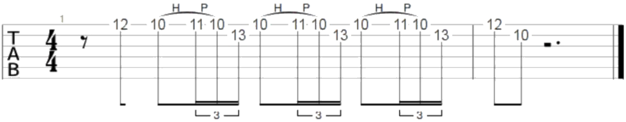
- Computer generation of melody has been studied since the early 1950's [7].
- Two approaches: explicit (in which composition rules are specified by humans) and implicit [8].
- Western music: features *counterpoint* (or *polyphony*), with multiple melodic voices [9].

Musical Phrases

- In *blues*, *jazz* and *rock* music, it's common to exist a "question/answer" dynamic with musical phrases:



(a) Antecedent phrase.



(b) Consequent phrase.

Figure 6: Examples of music tablature [10].

Assembling Maximum-length Tracks

- We'd like our model to capture the following restrictions:
  - A *consequent* phrase may only be played after an *antecedent* phrase, forming a *lick*;
  - Only phrases of the same type (*antecedent* or *consequent*) may be played simultaneously;
  - Phrases of different intensities (*e.g.* note counts) may not go well together;
  - The final composition must be a *loop*, include all phrases and be of maximum length.

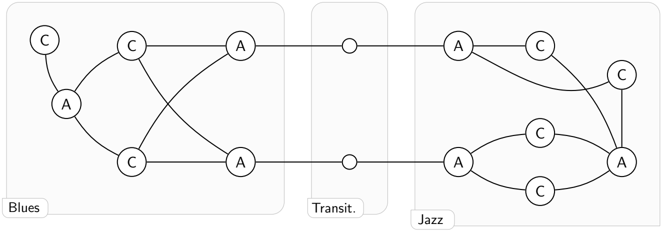


Figure 7: Modelling example.

Conclusion

- Contributions: computational strategy for obtaining minimum concurrency and new approach for creating musical tracks.
- The *MIDI* standard: hour-long tracks and potential source of inspiration for artists.
- Future work: computational model for maximum concurrency under *SER*; investigate octave information for better-quality polyphony.

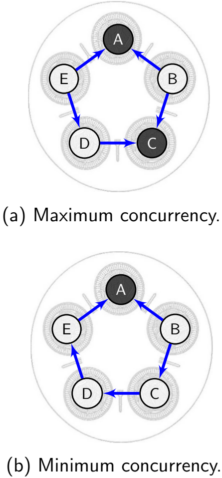


Figure 8: Extreme concurrencies.

Closure

Thank you!

Questions & Answers

This presentation is available in PDF format at:
https://tinyurl.com/inoc2019-32

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