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).

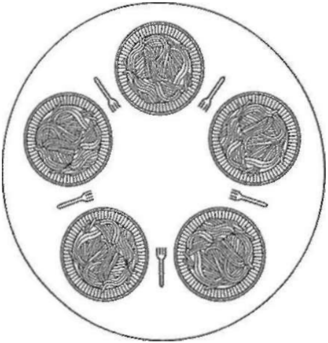


Figure 1:
The *Dining Philosophers* [1].

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?

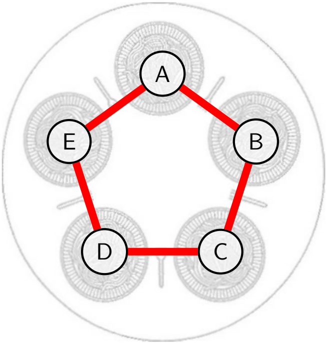


Figure 2: Resource Graph for the *Dining Philosophers*.

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.

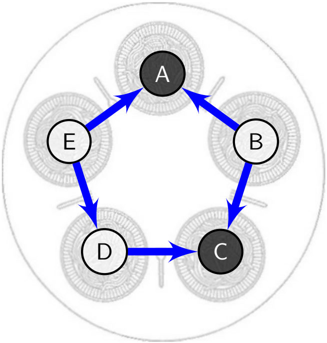
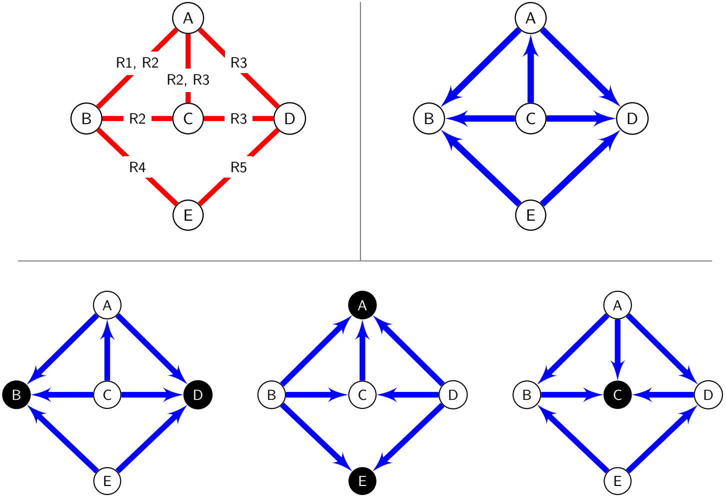
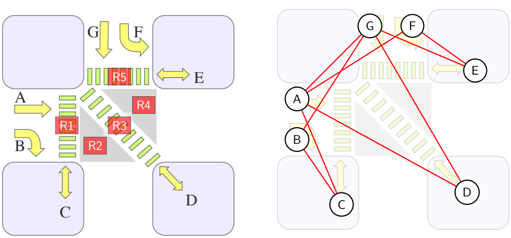


Figure 3: *DAG* representing the *Dining Philosophers.*

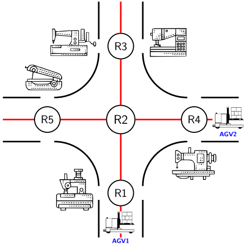
SER Example



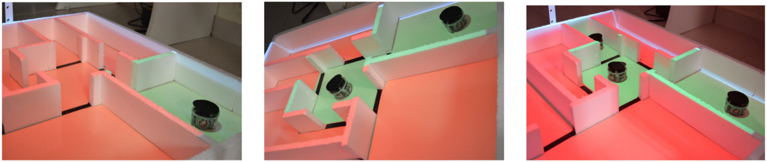
Applications



(d) Road junctions [2].



(e) AGV Routing [3].



(f) Firefighting by autonomous robots [4].

Figure 4: *SER* applications.

Definitions

Simple Cycle

$\cdots$

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

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

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

$\cdots$

K

Acyclic Orientation

$\cdots$

$\omega_3 : E \to V$

$\omega_1 : E \to V$

$\omega_2 : E \to V$

$\cdots$

Ω

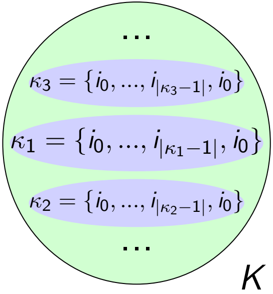
Direction of Orientation

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

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

Definitions

Simple Cycle



Acyclic Orientation

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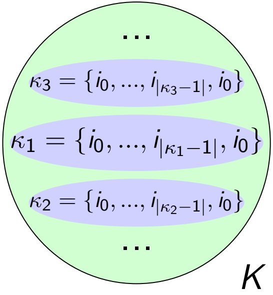
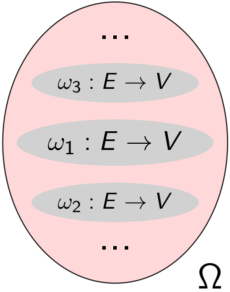
Definitions

Simple Cycle



Acyclic Orientation



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Definitions

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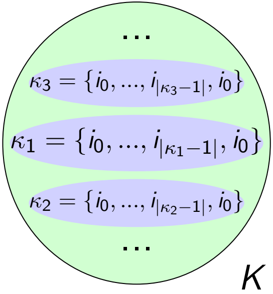
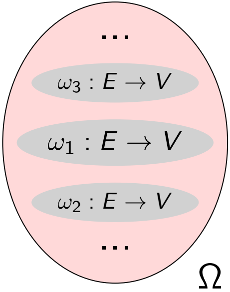
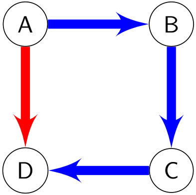


Acyclic Orientation



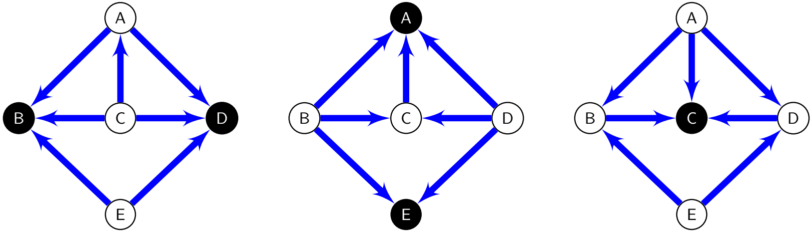
Direction of Orientation



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

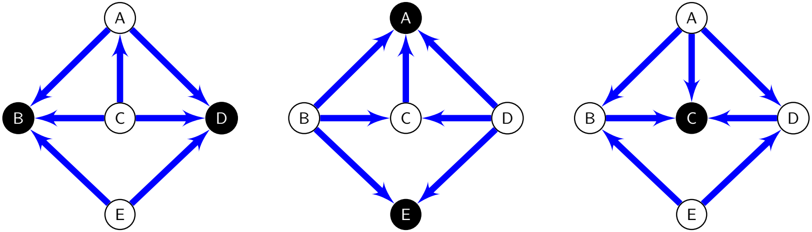
SER Concurrency ($\gamma : \Omega \to \mathbb{R}$), dynamic definition

$$\gamma(\omega) = \frac{m}{p}$$



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

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



Roadmap

Concorrência Mínima via Ciclos Máximos (1)

- NP-Completo [5]: Minimizar $\gamma(\omega)$ sobre todo o conjunto Ω:

$$\gamma^* = \min_{\omega \in \Omega} \left\{ \min_{\kappa \in K} \left\{ \frac{\min\{n_{cw}(\kappa,\omega), n_{ccw}(\kappa,\omega)\}}{|\kappa|} \right\} \right\} \quad (1)$$

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Lema 1

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

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

Demonstração

Relembre a definição de concorrência: $\gamma(\omega) = \min_{\kappa \in K} \left\{ \frac{\min\{n_{cw}(\kappa,\omega), n_{ccw}(\kappa,\omega)\}}{|\kappa|} \right\}$. Para um dado ω', seja κ' o ciclo escolhido pelo minimizador da definição de concorrência. Seja $x = \min\{n_{cw}(\kappa', \omega'), n_{ccw}(\kappa', \omega')\}$. Logo, temos $\gamma(\omega) = x/|\kappa'|$.

1/3

Concorrência Mínima via Ciclos Máximos (1)

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$$\gamma^* = \min_{\omega \in \Omega} \left\{ \min_{\kappa \in K} \left\{ \frac{\min\{n_{cw}(\kappa,\omega), n_{ccw}(\kappa,\omega)\}}{|\kappa|} \right\} \right\} \tag{1}$$

Lema 1

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

Demonstração

Porém, para qualquer ciclo $\kappa \in K$, é possível orientar κ com algum $\omega \in \Omega$ de forma que $n_{cw}(\kappa,\omega) = 1$ e $n_{ccw}(\kappa,\omega) = |\kappa| - 1$, ou vice-versa. Logo, se ω', aplicado a κ', não produziu o valor $x = 1$, haverá outra orientação $\omega \in \Omega$ que produzirá $\gamma(\omega) = 1/|\kappa'|$.

2/3

Concorrência Mínima via Ciclos Máximos (1)

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$$\gamma^* = \min_{\omega \in \Omega} \left\{ \min_{\kappa \in K} \left\{ \frac{\min\left\{n_{cw}(\kappa,\omega), n_{ccw}(\kappa,\omega)\right\}}{|\kappa|} \right\} \right\} \tag{1}$$

Lema 1

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

Demonstração

Suponha que $\gamma*$, a concorrência mínima de G, seja menor que $1/|\kappa'|$. Se isto for verdade, deverá existir um ciclo κ^* que, sob alguma orientação $\omega*$, produzirá $1/|\kappa^*| < 1/|\kappa'|$. Logo, encontrar γ^* tornou-se um problema de minimização sobre todo $\kappa \in K$. $\square$

Concorrência Mínima via Ciclos Máximos (2)

- Resta encontrar ω^* tal que $\gamma^* = \gamma(\omega^*)$.

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Teorema 1

Dado qualquer ciclo máximo $\kappa^* \in K$ como entrada, existe um algoritmo de complexidade linear para encontrar uma orientação $\omega^* \in \Omega$ tal que $\gamma(\omega^*)$ é mínimo para todo $\omega \in \Omega$.

Concorrência Mínima via Ciclos Máximos (2)

- Resta encontrar ω^* tal que $\gamma^* = \gamma(\omega^*)$.

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Demonstração

Pela prova do Lema 1, para atingir γ^*, deve-se orientar κ^* tal que $n_{cw}(\kappa^*, \omega^*) = 1$ e $n_{ccw}(\kappa^*, \omega^*) = |\kappa^*| - 1$ (ou vice-versa). Isto pode ser realizado em tempo linear ao percorrermos o ciclo κ^* e atribuirmos um número de identificação crescente $1, \dots, |\kappa^*|$ para cada vértice visitado, resultando em uma ordenação topológica do ciclo. Por fim, orienta-se as arestas no sentido dos vértices de maior identificador, cumprindo o requisito. 1/2

Concorrência Mínima via Ciclos Máximos (2)

- Resta encontrar ω^* tal que $\gamma^* = \gamma(\omega^*)$.

Teorema 1

Dado qualquer ciclo máximo $\kappa^* \in K$ como entrada, existe um algoritmo de complexidade linear para encontrar uma orientação $\omega^* \in \Omega$ tal que $\gamma(\omega^*)$ é mínimo para todo $\omega \in \Omega$.

Demonstração

Resta orientar os demais vértices de G tal que ω^* sempre será de fato acíclica. Seja $S = V - \kappa^*$ o conjunto dos vértices restantes de G. Atribui-se um número de identificação crescente $|\kappa^*| + 1, ..., |V|$ para cada vértice em S, e então orienta-se todas as arestas de G na direção dos vértices com maior identificador. Por absurdo, se ω^* possuir ciclos, existirá um caminho direcionado $i_0, i_1, ..., i_0$. No entanto, como $id[i_0] > id[i_1]$, é impossível retornar a i_0 após a partida, para qualquer $i_0 \in V$. Portanto, nenhum ciclo será formado. $\square$

Experimental Results

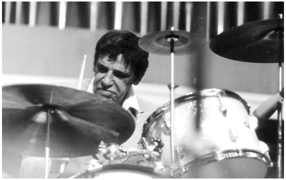
- *Simple Cycle Problem* model from Lucena et al. [6]:

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



(e) Buddy Rich, jazz.

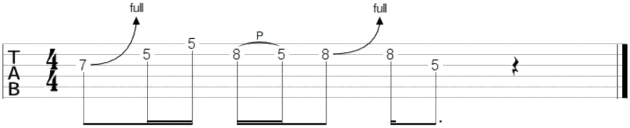
(f) Joe Bonamassa, blues.

Figure 5: Virtuosos *(Creative Commons)*.

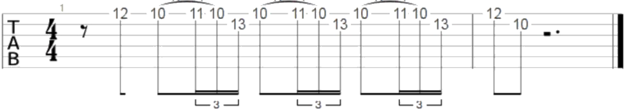
- Computer generation of melody has been studied since the early 1950's [7].
- Two approaches: explicit (in which composition rules are specified by humans) and implicit [8].
- Western music: features *counterpoint* (or *polyphony*), with multiple melodic voices [9].

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.

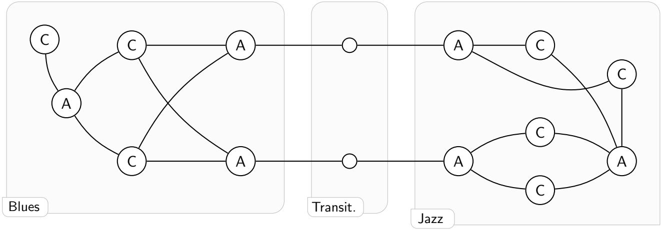
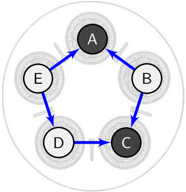


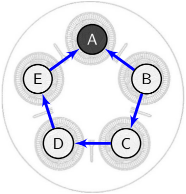
Figure 7: Modelling example.

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.



(a) Maximum concurrency.



(b) Minimum concurrency.

Figure 8: Extreme concurrencies.

Closure

Thank you!

Questions & Answers

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https://tinyurl.com/inoc2019-32

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