network *blockmodeling*

introduction to *network analysis* (*ina*)

Lovro Šubelj
University of Ljubljana
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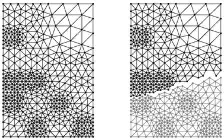
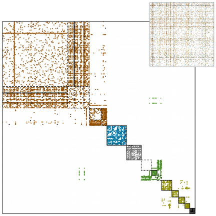
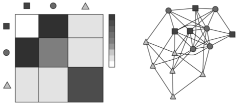
blockmodeling *overview*



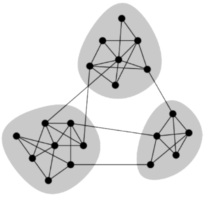
graph partitioning [KL70, Fie73]



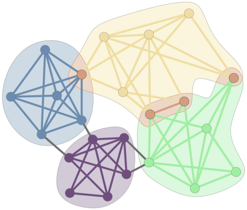
blockmodeling [LW71, WR83]



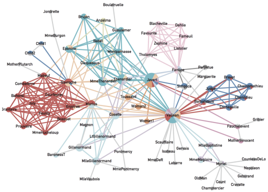
stochastic block model [Pei15]



communities [GN02]



overlapping communities [PDFV05]



link communities [EL09, ABL10]

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* assortative & disassortative equivalence blockmodeling

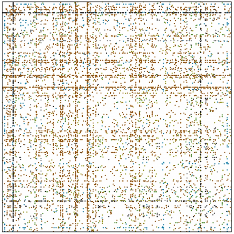
blockmodeling *equivalence*

— *standard equivalence blockmodeling* [DBF05]

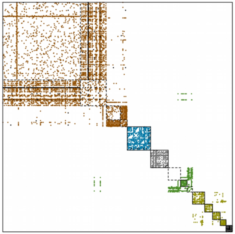
– define *node similarity* as *(structural) equivalence*

$$\sigma_{ij} \sim |\Gamma_i \cap \Gamma_j|$$

1. *blockmodeling* by *(hierarchical) clustering* $\mathcal{O}(n^2)$
2. return *block model* at desired *clustering resolution*



javax adjacency matrix



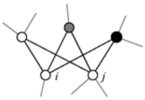
javax block model

‡ `javax.swing`, `javax.management`, `javax.naming`, `javax.print`, `javax.xml`, `javax.lang` etc.

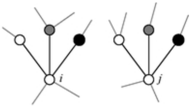
blockmodeling *structural*

similar nodes have *same neighbors*

- *standard structural equivalence* [LW71] of i and j is
  $$\sigma_{ij} = \sum_x A_{ix} A_{xj} = |\Gamma_i \cap \Gamma_j|$$
- *Salton structural equivalence* [SM83] of i and j is
  - θ_{ij} is *angle* between neighborhoods A_i and A_j
  $$\sigma_{ij} = \cos\theta_{ij} = \frac{\sum_x A_{ix} A_{xj}}{\sqrt{\sum_x A_{ix}^2}\sqrt{\sum_x A_{jx}^2}} = \frac{|\Gamma_i \cap \Gamma_j|}{\sqrt{k_i k_j}}$$
- *Leicht structural equivalence* [LHN06] of i and j is $\sigma_{ij} = \frac{|\Gamma_i \cap \Gamma_j|}{k_i k_j / n}$



structural



regular equivalence

blockmodeling *regular*

similar nodes have *equivalent* *neighbors*

- *standard regular equivalence* [WR83] of i and j is
  - $\alpha < \lambda^{-1}$ is *positive constant* and λ *leading eigenvalue* of A

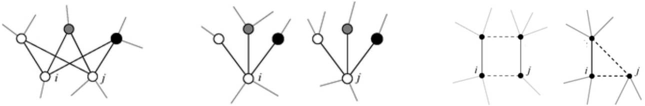
$$\sigma_{ij} = \alpha \sum_{xy} A_{ix} A_{jy} \sigma_{xy} + \delta_{ij} = \alpha \sum_{x \in \Gamma_i} \sum_{y \in \Gamma_j} \sigma_{xy} + \delta_{ij}$$

$\sigma = \alpha A \sigma A + I$ and thus $\sigma^{(0)} = 0$, $\sigma^{(1)} = I$, $\sigma^{(2)} = \alpha A^2 + I$, $\sigma^{(3)} = \alpha^2 A^4 + \alpha A^2 + I$ etc.

- *Katz regular equivalence* [Kat53] of i and j is

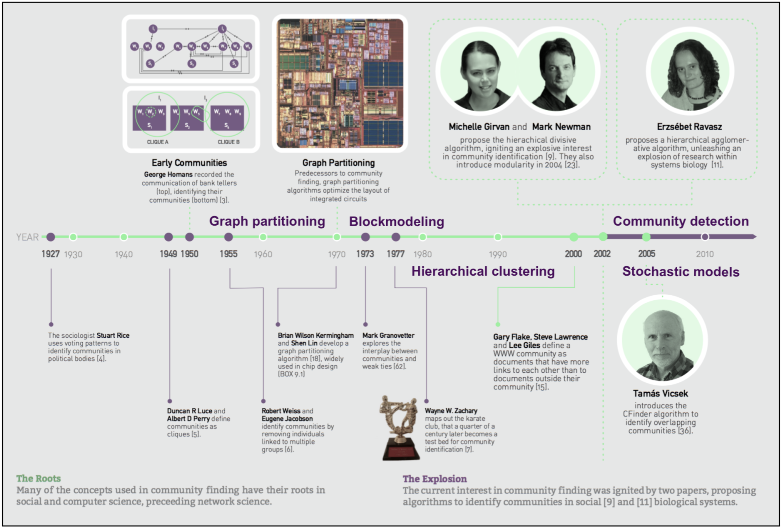
$$\sigma_{ij} = \alpha \sum_{x} A_{ix} \sigma_{xj} + \delta_{ij} = \alpha \sum_{x \in \Gamma_i} \sigma_{xj} + \delta_{ij}$$

$\sigma = \alpha A \sigma + I$ and thus $\sigma^{(0)} = 0$, $\sigma^{(1)} = I$, $\sigma^{(2)} = \alpha A + I$, $\sigma^{(3)} = \alpha^2 A^2 + \alpha A + I$ etc.



structural regular equivalence standard Katz

blockmodeling *history*



stochastic models

introduction to *network analysis* (*ina*)

Lovro Šubelj
University of Ljubljana
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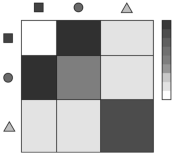
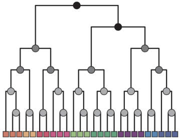
stochastic *models*

- *random graph model* $G(n,m)$ for *network links* m [ER59]
- *configuration model* $G(\{k\})$ for *node degrees* $\{k\}$ [NSW01]
- *exponential* p^**-model* $G(n,\{\langle x\rangle\})$ for *any expectations* $\{\langle x\rangle\}$

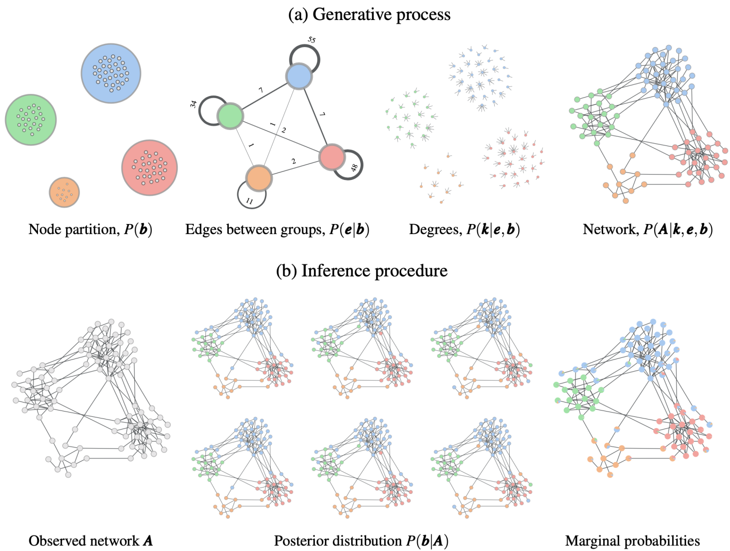
- *stochastic block model* $G(\{C\})$ for *node clusters* $\{C\}$ [HLL83]
- *hierarchical model* $G(H)$ for *node hierarchy* H [CMN08]





*assortative & disassortative stochastic block models

stochastic *process*



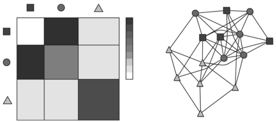
stochastic $G(\{C\})$ model

- $G(\{C\},\{p\})$ *stochastic block model* [HLL83]
- *link* between i and j *placed with probability* $p_{c_i c_j}$
  - $m_{c_i c_j}$ is *number of links* between C_i and C_j
  - $M_{c_i c_j}$ is *maximum* $m_{c_i c_j}$ hence $n_i n_j$ or $\binom{n_i}{2}$

$$\mathrm{P}(A|\{C\},\{p\}) = \prod_{i \leq j} p_{c_i c_j}^{A_{ij}} (1 - p_{c_i c_j})^{1-A_{ij}} = \prod_{c_i \leq c_j} p_{c_i c_j}^{m_{c_i c_j}} (1 - p_{c_i c_j})^{M_{c_i c_j} - m_{c_i c_j}}$$

- *maximum likelihood* $G(\{C\})$ *block model*
  - $\frac{m_{c_i c_j}}{M_{c_i c_j}}$ is *maximum likelihood estimate* for $p_{c_i c_j}$

$$\mathcal{L}(A|\{C\}) = \log \mathrm{P}(G|\{C\}) = \sum_{c_i \leq c_j} m_{c_i c_j} \log \frac{m_{c_i c_j}}{M_{c_i c_j} - m_{c_i c_j}} + M_{c_i c_j} \log \frac{M_{c_i c_j} - m_{c_i c_j}}{M_{c_i c_j}}$$



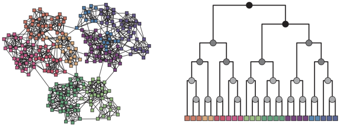
see graph-tool implementation

stochastic $G(H)$ *model*

- $G(H, \{p\})$ *hierarchical model* [CMN08]
- *link* between i and j *placed with probability* $p_{r_{ij}}$
  - r is *root with subtrees* L_r, R_r and r_{ij} *lowest root* of i and j
  - m_r is *number of links* between L_r, R_r and M_r is $|L_r||R_r|$

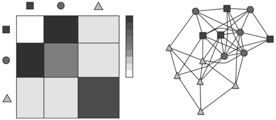
    $\mathrm{P}(A|H, \{p\}) = \prod_{i \leq j} p_{r_{ij}}^{A_{ij}} (1 - p_{r_{ij}})^{1-A_{ij}} = \prod_r p_r^{m_r} (1 - p_r)^{M_r - m_r}$
- *maximum likelihood* $G(H)$ *hierarchical model*
  - $\frac{m_r}{M_r}$ is *maximum likelihood estimate* for p_r

    $\mathcal{L}(A|H) = \log \mathrm{P}(G|H) = \sum_r m_r \log \frac{m_r}{M_r - m_r} + M_r \log \frac{M_r - m_r}{M_r}$

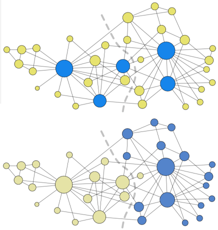


see randomgraphs implementation

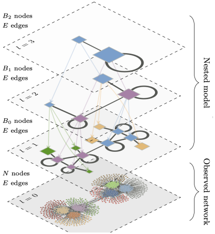
stochastic *overview*



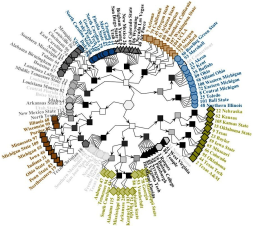
stochastic block model [HLL83]



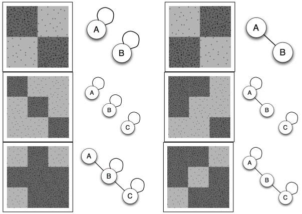
degree-corrected SBM [KN11]



nested SBM [Pei15]



hierarchical models [CMN08, ŠB14]



role models [RW07, NL07, GSPA07]

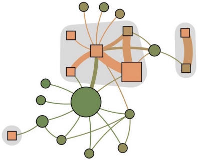


image graphs [ŠB12]

† overlapping & corrected models also known as mixture & mixed membership models

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