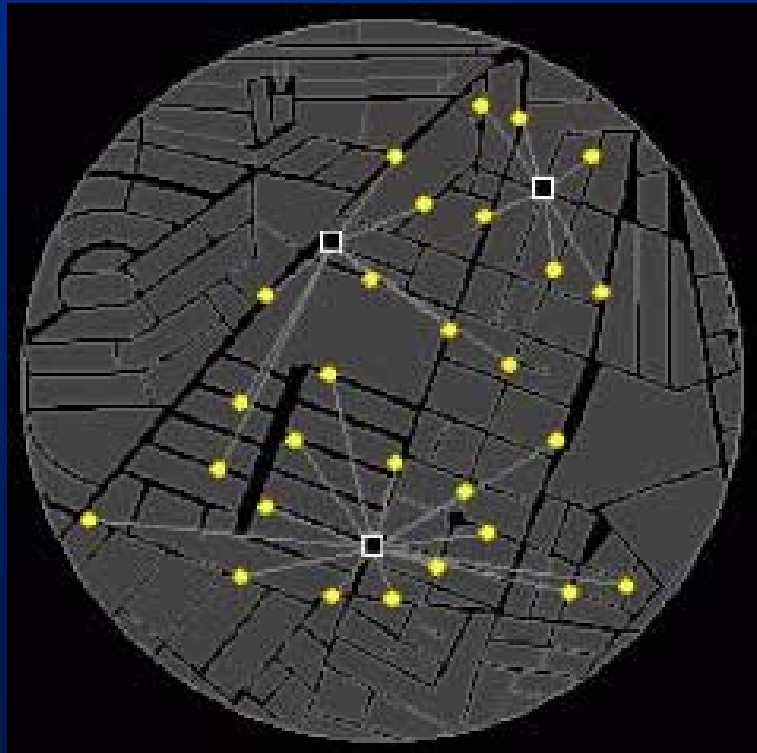


Análise de redes com Sistemas de Informações Geográficas

Integrações e Algoritmos



Luiz A. N. Lorena

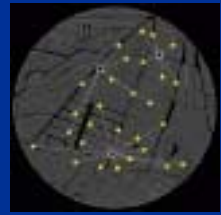
lorena@lac.inpe.br

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LAC/INPE

2001

Análise de redes com Sistemas de Informações Geográficas



■ Projetos temáticos FAPESP

<http://www.lac.inpe.br/~lorena/ArsigIndex.html>

■ ARSIG - Análise de redes com SIGs

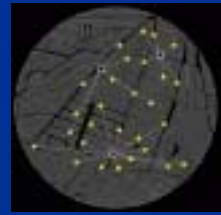
julho/97 a junho/99

■ ARSIG2 - Sistemas de Apoio à Decisão usando Redes e SIGs

julho/2000 a junho/2002

ARSIG e ARSIG2

Equipe



■ **Coordenador ARSIG:**
Luiz Antonio Nogueira Lorena

Colaboradores por Instituição:
INPE

- Luiz Antonio Nogueira Lorena
- Horácio Hideki Yanasse
- M. de Lourdes N. Kurkdjian
- Acioli Antonio de Olivo

FEG/UNESP

- Edson L. França Senne
- Edgard Dias B. Júnior

■ **Coordenador ARSIG2:**
Luiz Antonio Nogueira Lorena

Colaboradores por Instituição:
INPE

- Luiz Antonio Nogueira Lorena
- Horácio Hideki Yanasse
- João Argemiro de C. Paiva
- Marcos Antonio Pereira, MSc

FEG/UNESP

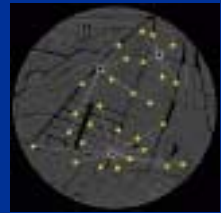
- Edson L. França Senne
- Edgard Dias B. Júnior
- José Celso Freire Júnior

EMBRAPA

- Marcelo Gonçalves Narciso

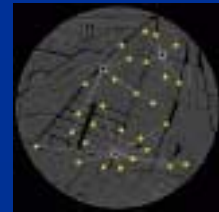
ARSIG e ARSIG2

Sumário



- Integração de grupos de pesquisa na área de Pesquisa Operacional: problemas de redes que aparecem no ambiente de Sistemas de Informações Geográficas.
- O propósito final é dotar decisores de ferramentas úteis na solução de problemas de localização de facilidades, roteamento de veículos, problemas de transportes e problemas relacionados.
- aplicações no ambiente urbano, levando em consideração sua malha viária, com dados e mapas digitalizados.
- iniciada a identificação e solução de problemas que envolvem redes no ambiente agrícola.
- novos algoritmos desenvolvidos com sucesso por membros da equipe, com diversas aplicações nas áreas assinaladas.
- coleta e análise de dados que podem ser referenciados geograficamente.

Sistemas de Informações Geográficas



■ ArcView



- SIG para microcomputadores
- O módulo de redes não contempla problemas de localização e roteamento.

■ MapObjects

- Permite a integração direta de um SIG com ambientes de desenvolvimento tipo *Visual Basic*, *Delphi* ou *Visual C++*.

<http://www.esri.com>

■ SPRING



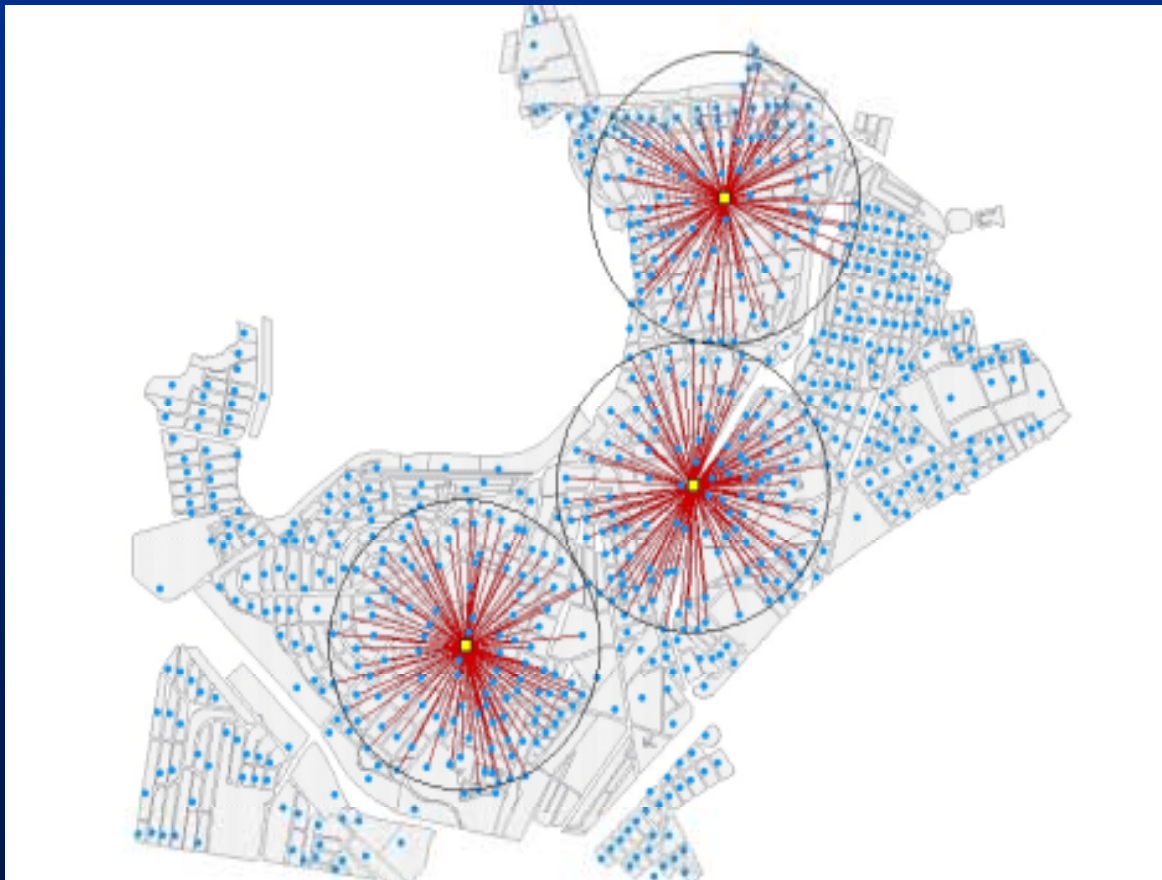
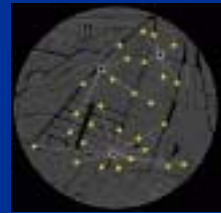
- É um banco de dados geográfico de 2º geração, para ambientes *Windows* e *Unix*.
- Desenvolvido no INPE

<http://www.dpi.inpe.br/spring>

- Iniciar estudos para integração dos algoritmos a outros SIGs:

[MapInfo](#) e [TransCAD](#)

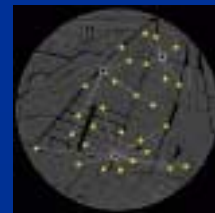
Problemas de Localização



- Problemas de cobertura
- Problema de máxima cobertura
- Demandas, distancias e distancia de serviço
- P-medianas
- Distancias e demandas

Integrações

Máxima Cobertura



Número de facilidades

Entre com o número de facilidades:

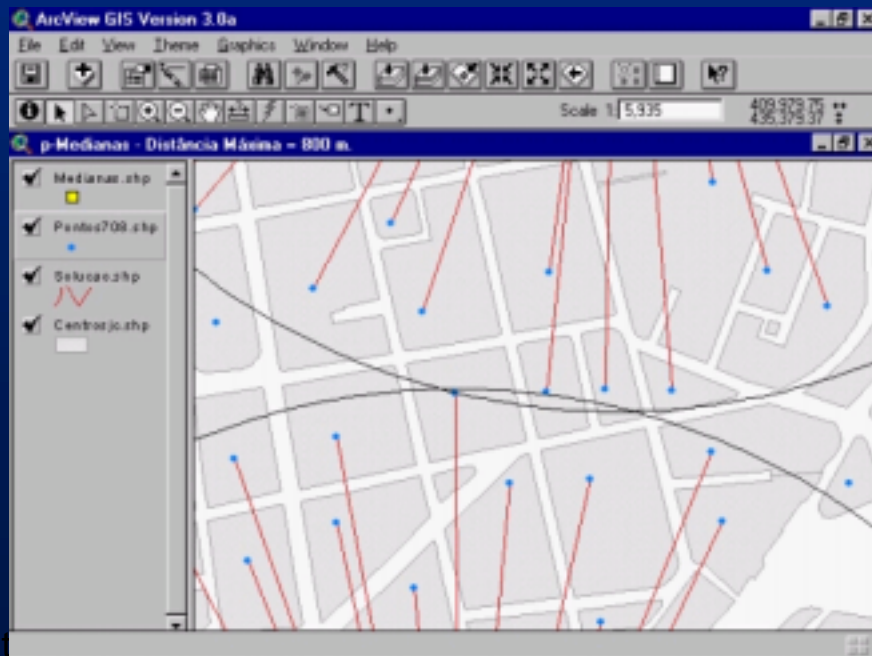
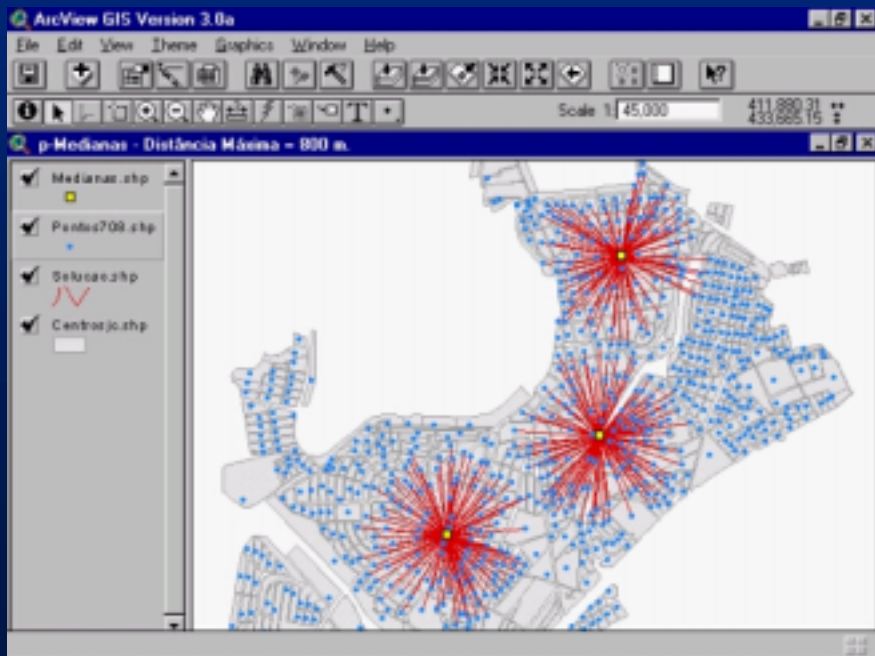
OK Cancel

Distância Máxima

Entre com a distância máxima de atendimento (em metros):

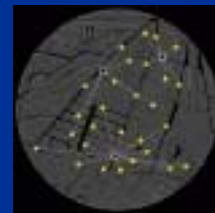
OK Cancel

- Integração de algoritmo de Máxima Cobertura ao ArcView

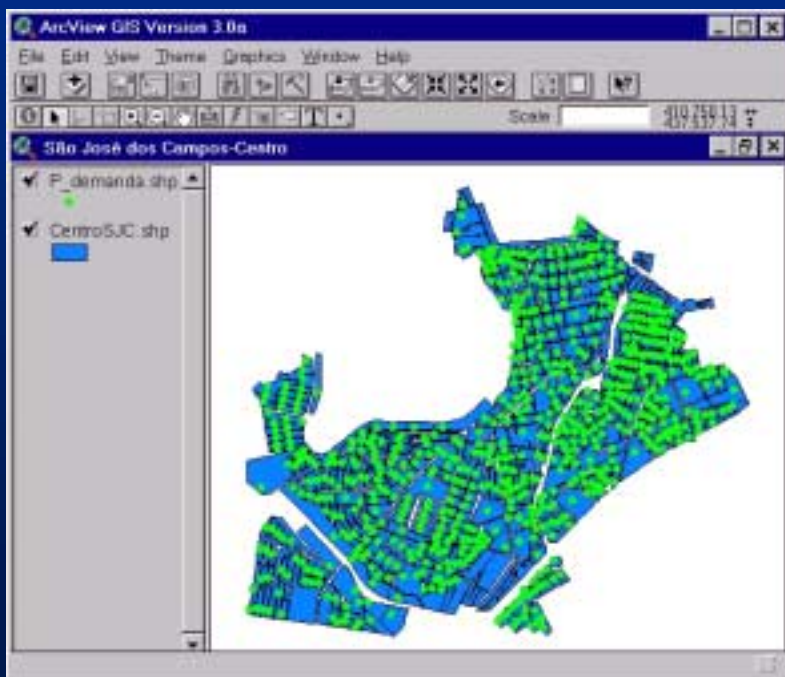
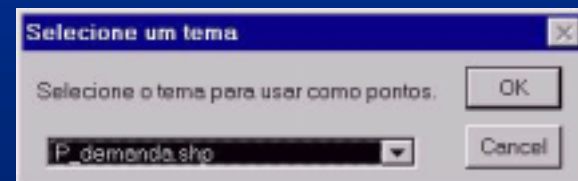
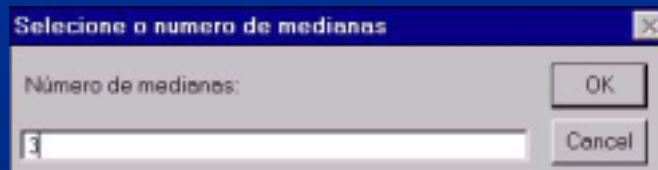


Integrações

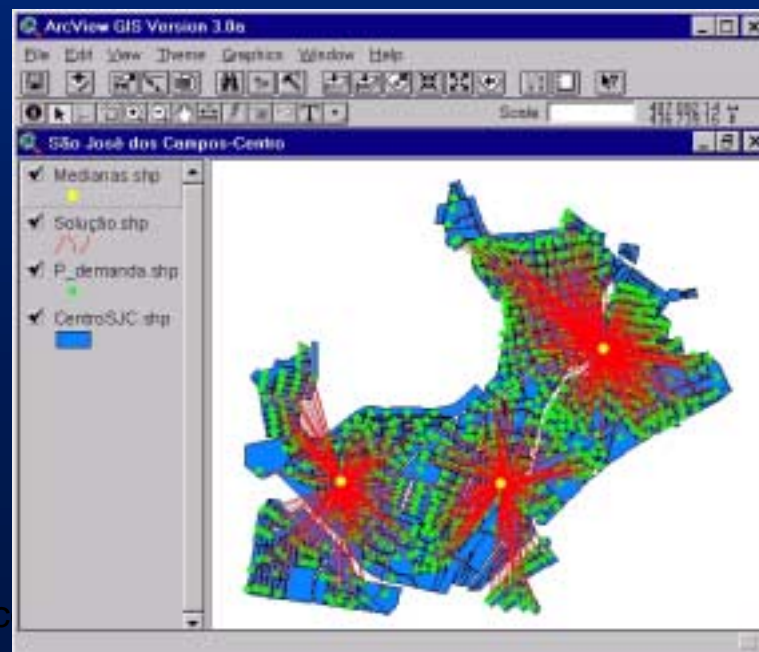
P-medianas



- Integração de algoritmo de p-medianas ao ArcView

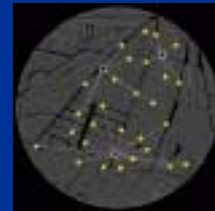


Distancias euclidianas

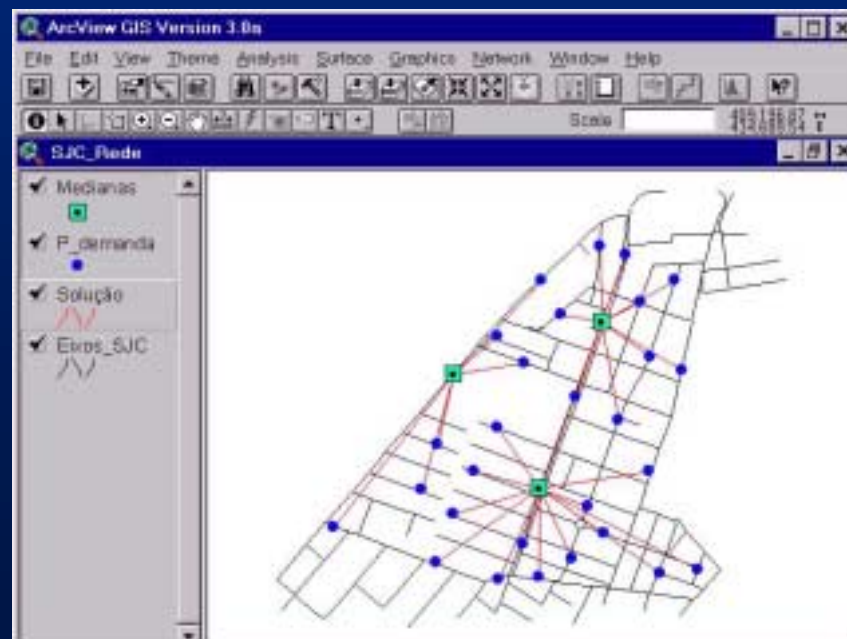
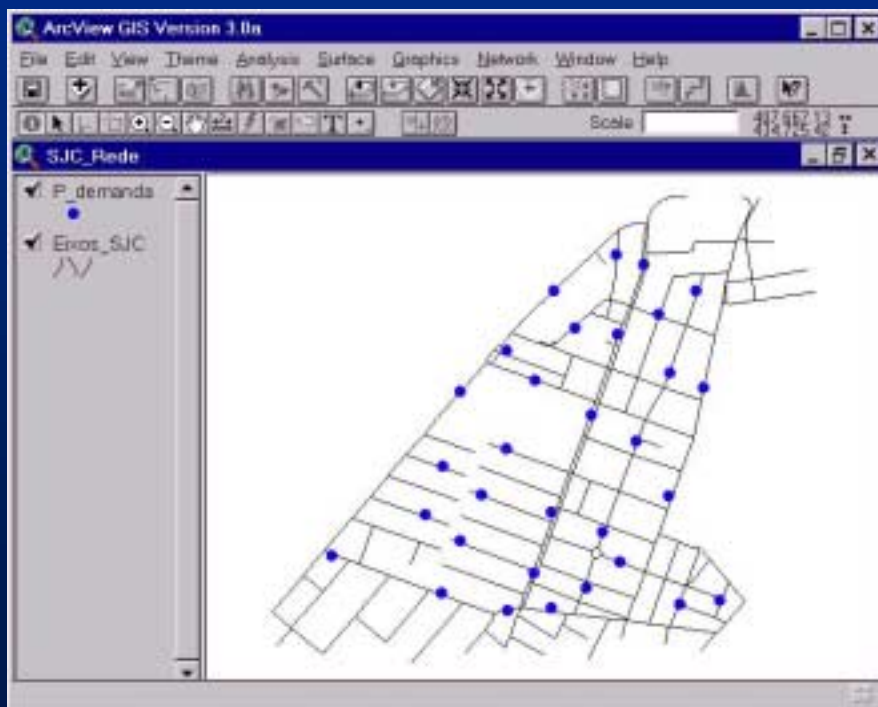
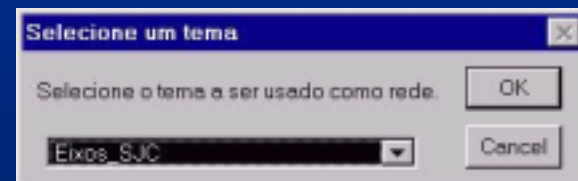
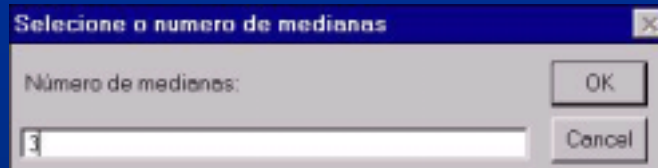


Integrações

P-medianas



Integração de algoritmo de p-medianas ao ArcView

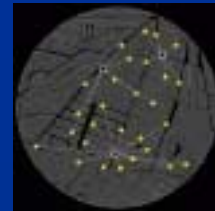


Distancias de rede

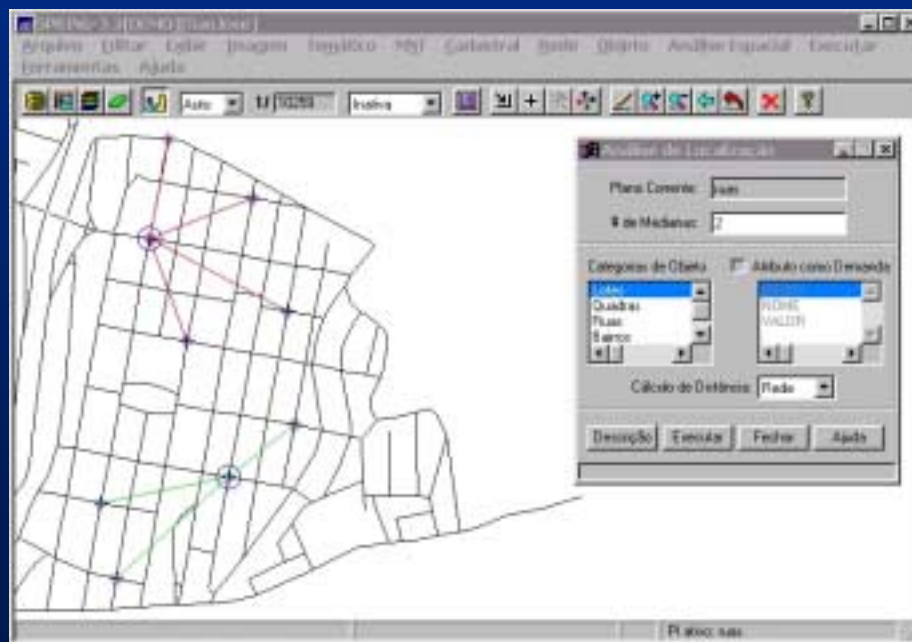
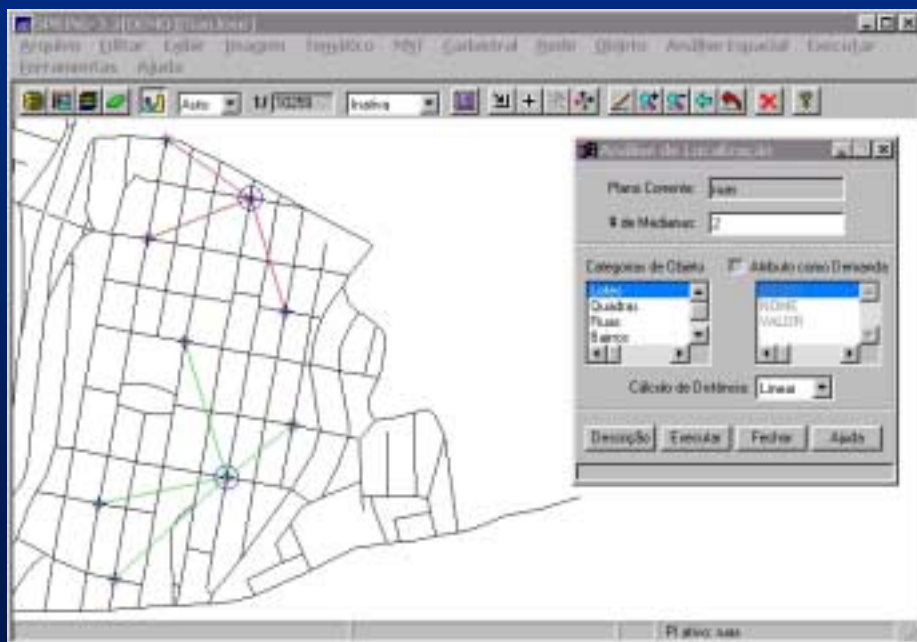
ARSIG - temático

Integrações

P-medianas

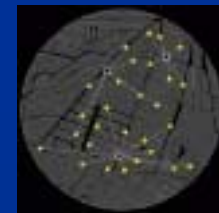


- Integração de algoritmo de p-medianas ao SPRING

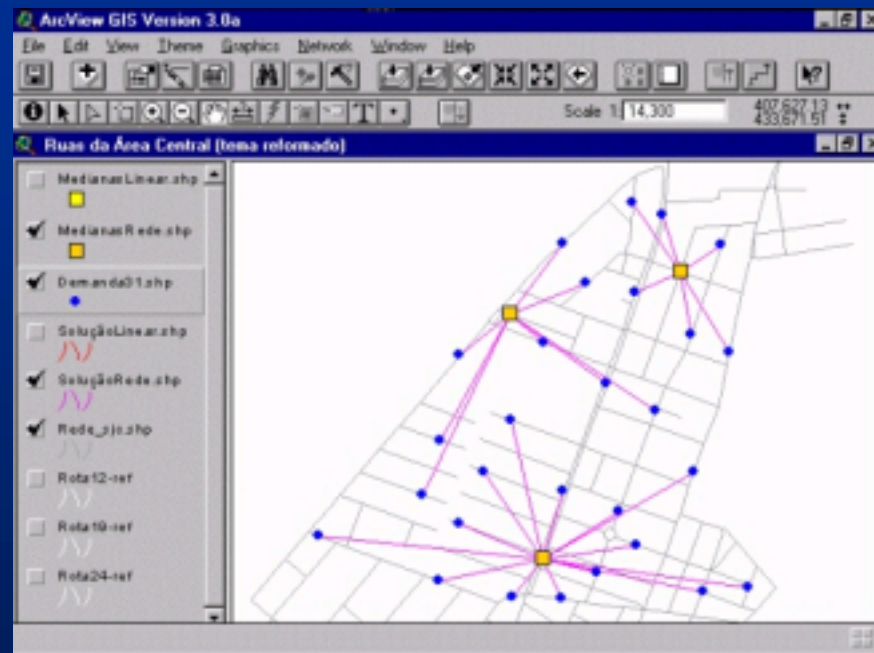
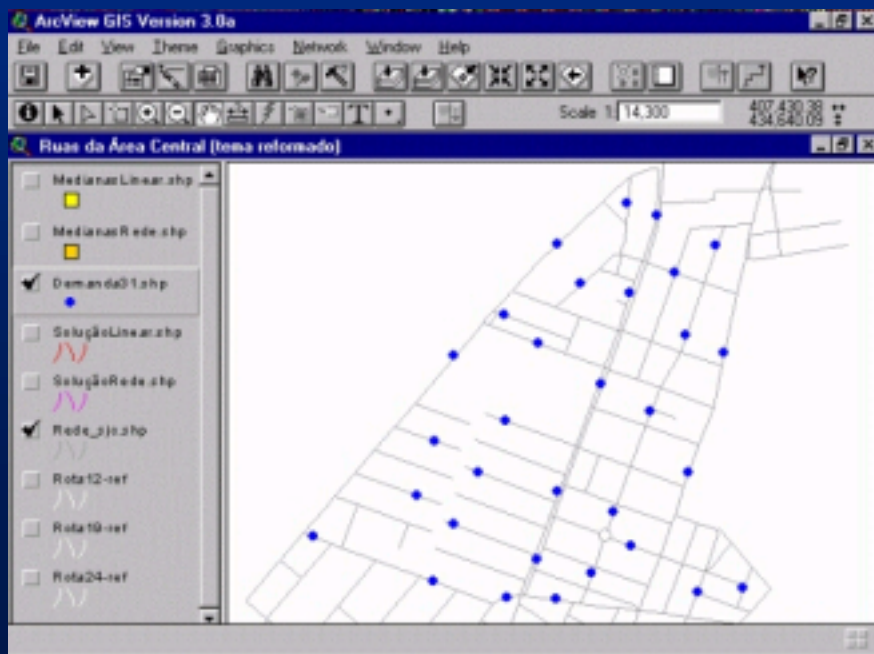


Integrações

P-medianas



- Integração de algoritmo de p-medianas capacitado ao ArcView



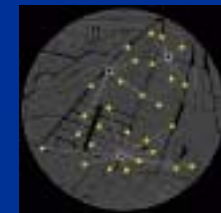
Identify Results

ID	Shape	Point
1: Demanda100.shp - 74	Point	409765
	Coordx	435617
	Coordy	720
	Capacidade	28
	Demanda	

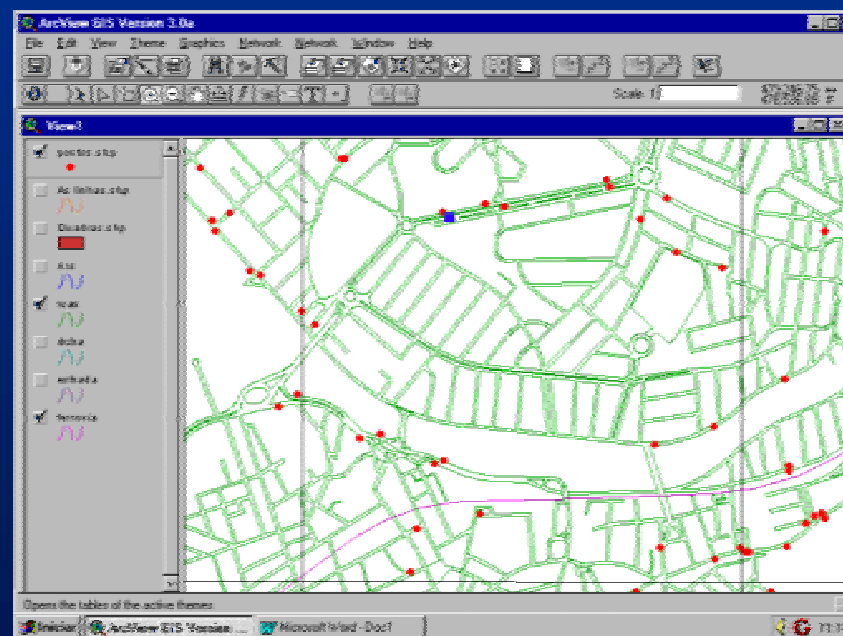
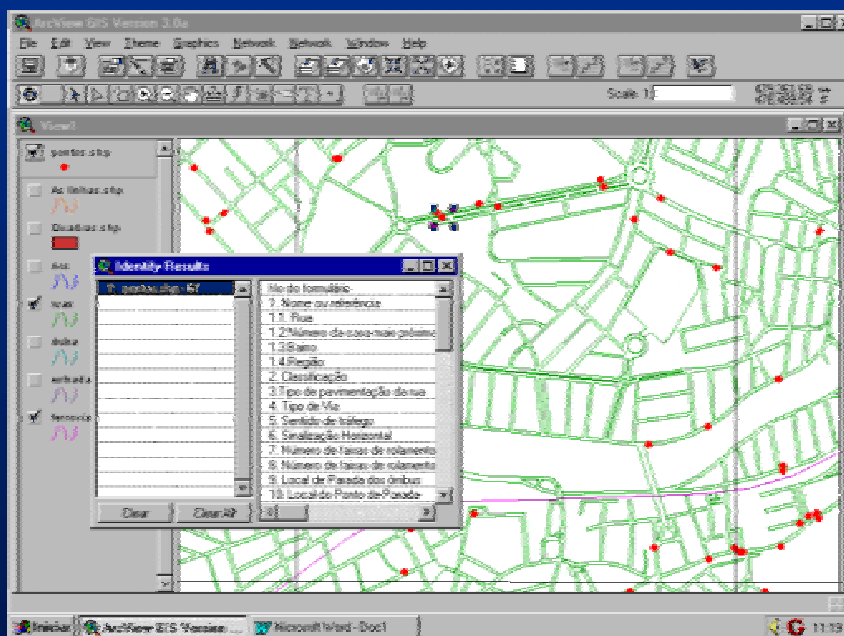
Clear Clear All

Localização - pontos de parada

Coleta de dados - Guaratinguetá

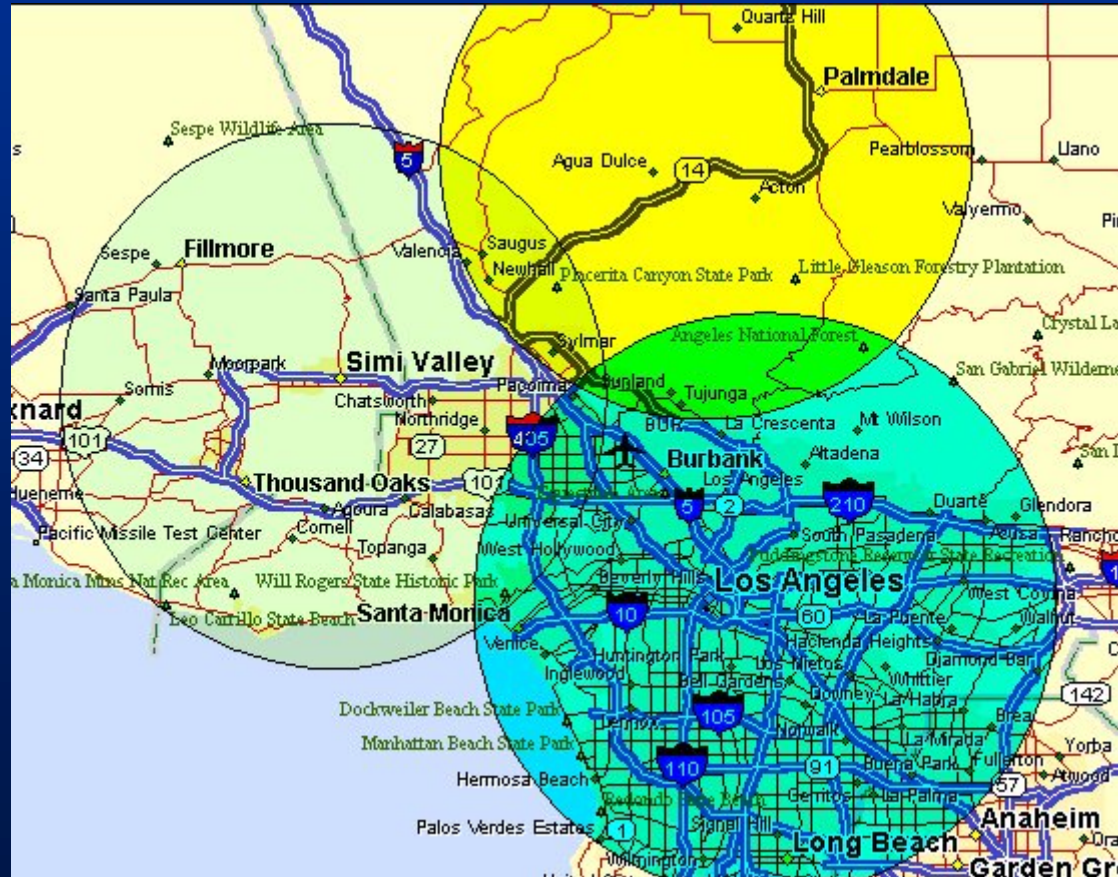
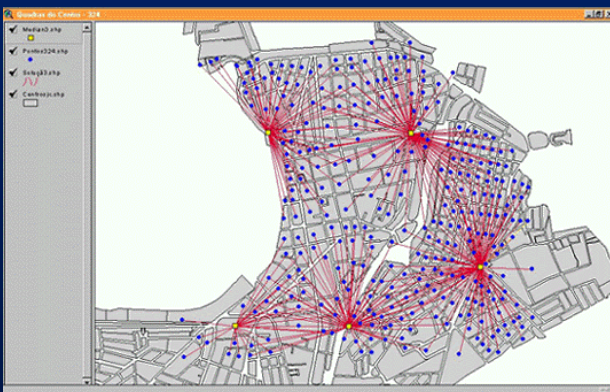
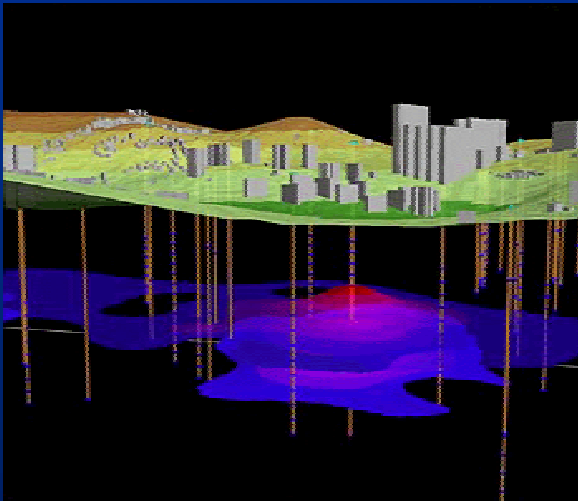
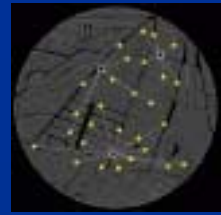


(Transportes)



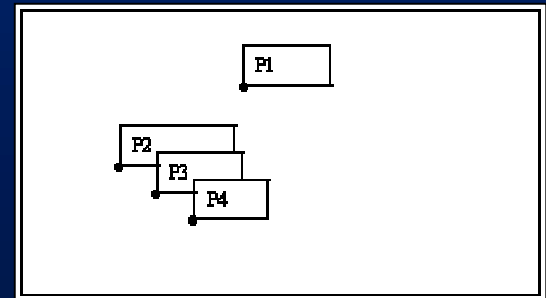
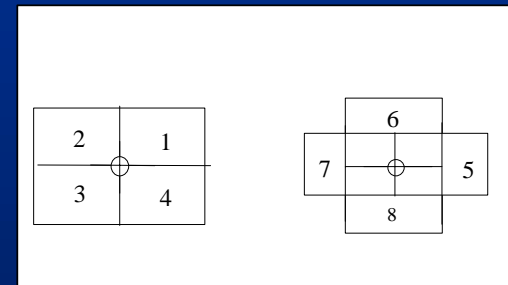
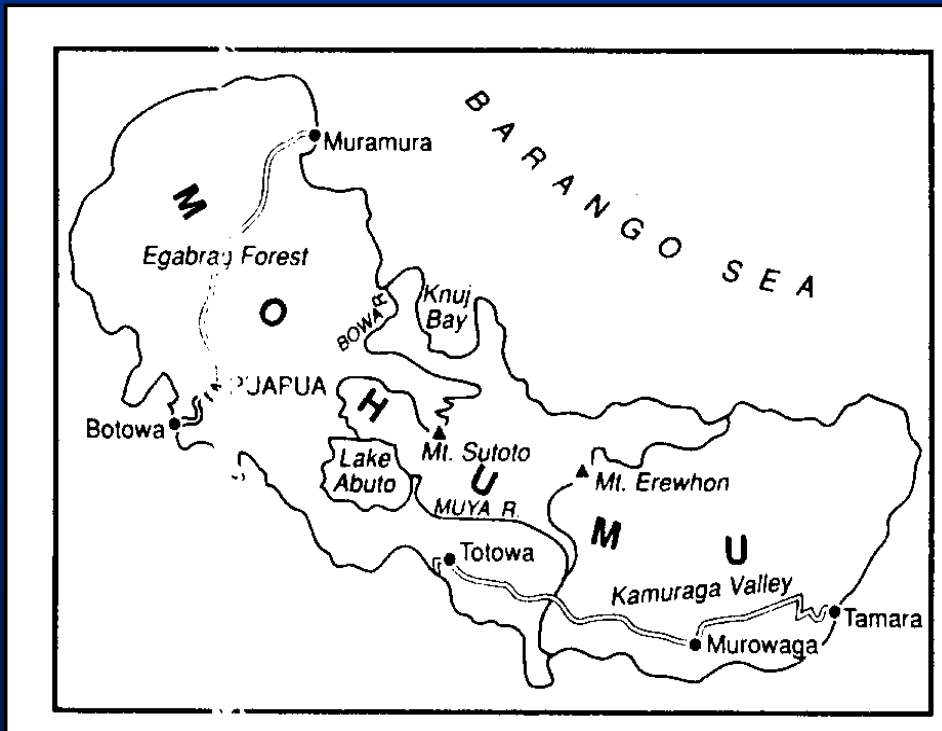
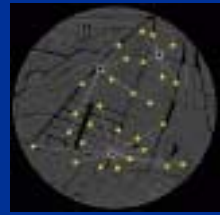
Problema de Localização de Antenas

Aplicações



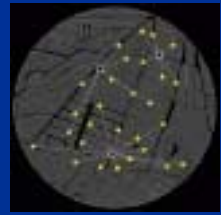
Rotulação de mapas

Aplicações



Rotulação de mapas

Aplicações

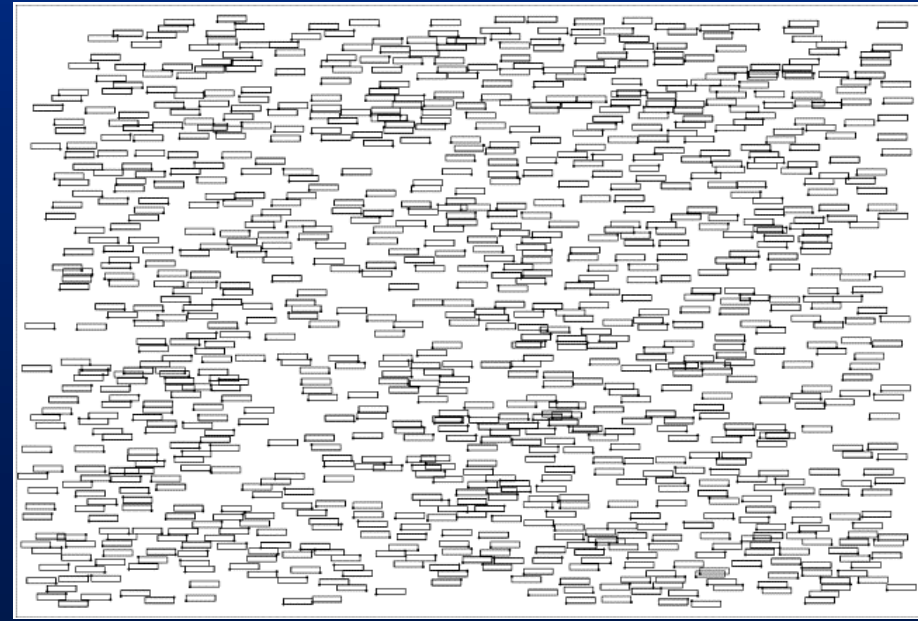
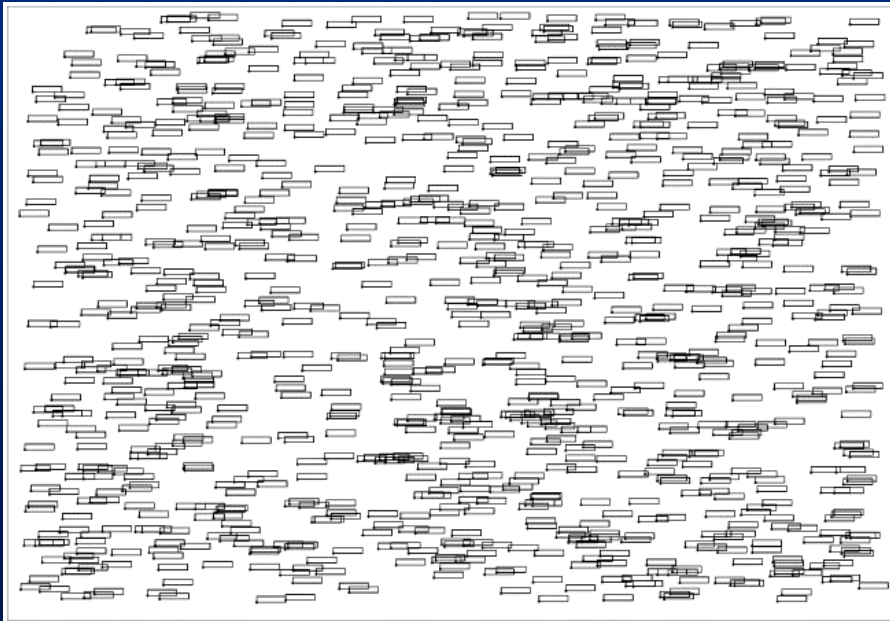


■ 1000 pontos

■ conflitos = 703

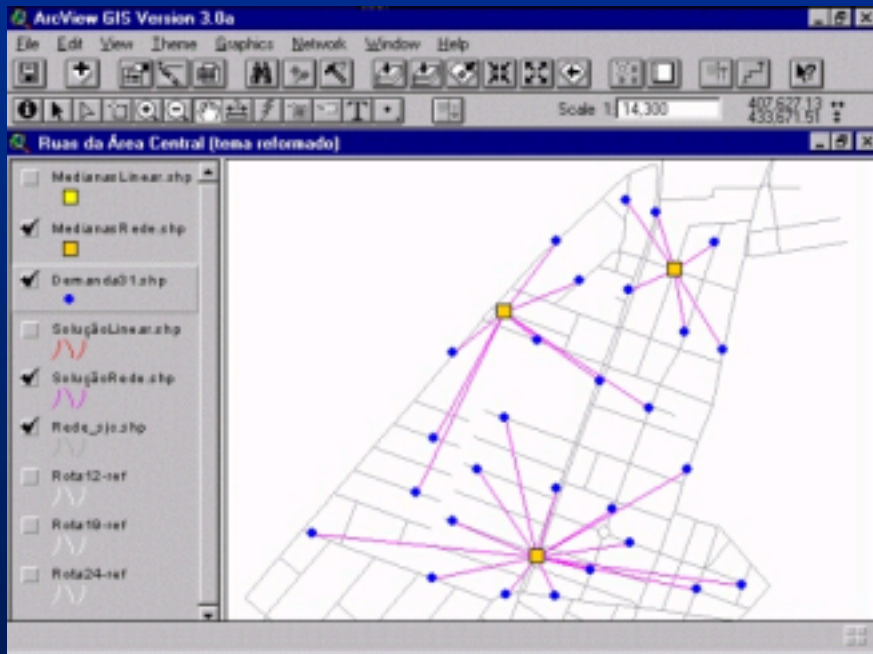
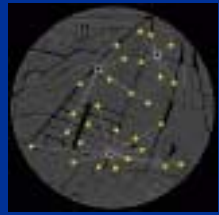
■ 1000 pontos

■ conflitos = 77

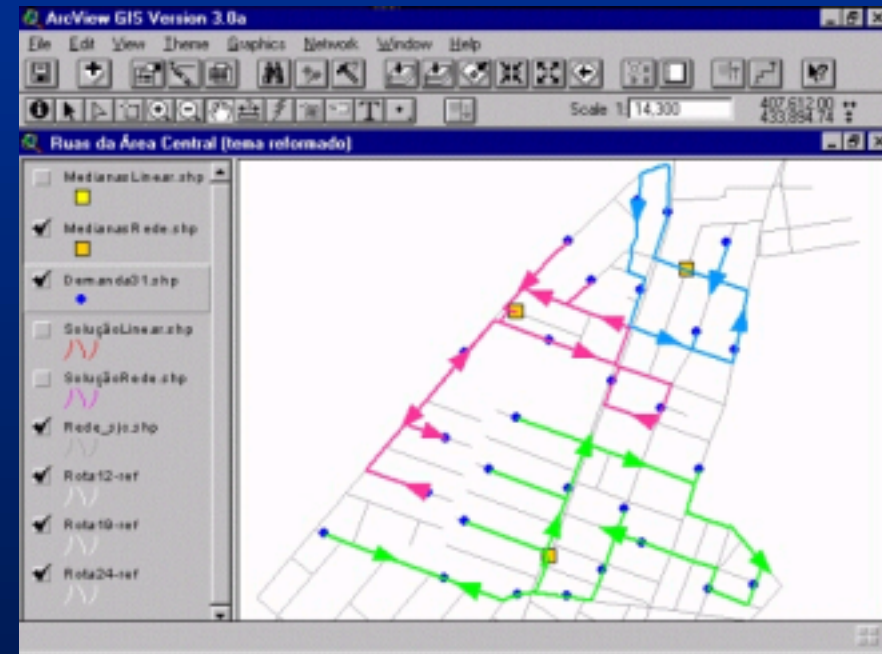


Localização/roteamento

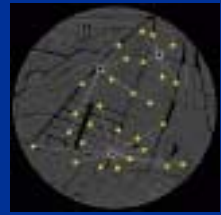
Aplicações



P-mediana capacitado



Roteamento de veículos

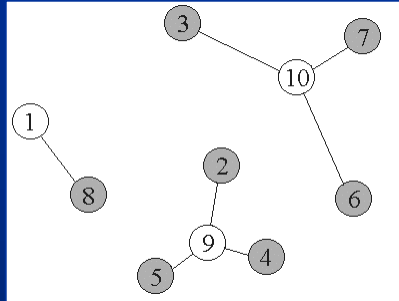
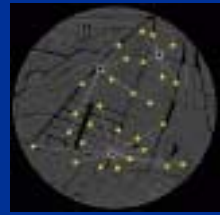


- Decisões sobre onde localizar facilidades, considerando clientes que devem ser servidos de forma a otimizar algum critério.
- O termo “facilidades” é utilizado para designar fábricas, depósitos, escolas etc., enquanto “clientes” refere-se a depósitos, unidades de vendas, estudantes etc.
- O problema das p -medianas

é um problema clássico e consiste em localizar p facilidades (medianas) em uma rede, de modo a minimizar a soma das distâncias de cada nó de demanda à sua mediana mais próxima.

P-medianas

(formul ações)



(P)

sujeito a:

given $\lambda \in R_+^n$, $t > 0$,

$$\sum_{j=1}^n \sum_{i=1}^n \lambda_j x_{ij} = \sum_{j=1}^n \lambda_j$$

$$v(L_t SP^\lambda) = \min \sum_{j=1}^n \sum_{i=1}^n (d_{ij} - t\lambda_j) x_{ij} + t \sum_{j=1}^n \lambda_j$$

$$v(P) = \mathbf{Min} \sum_{i=1}^n \sum_{j=1}^n d_{ij} x_{ij}$$

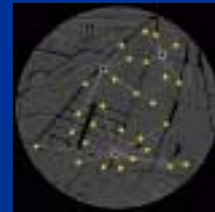
$$\sum_{j=1}^n x_{ij} = 1, \quad \forall i \in N$$

$$\sum_{j=1}^n x_{jj} = p$$

$$x_{ij} \leq x_{jj}, \quad \forall i, j \in N, i \neq j$$

$$x_{ij} \in \{0, 1\}, \quad \forall i, j \in N$$

Relaxações

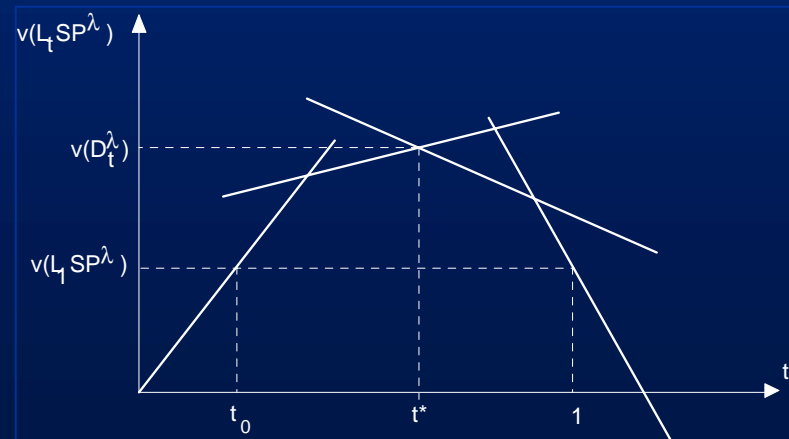


$$v(L_t SP^\lambda) = \min \sum_{j=1}^n \sum_{i=1}^n (d_{ij} - t\lambda_j) x_{ij} + t \sum_{j=1}^n \lambda_j$$

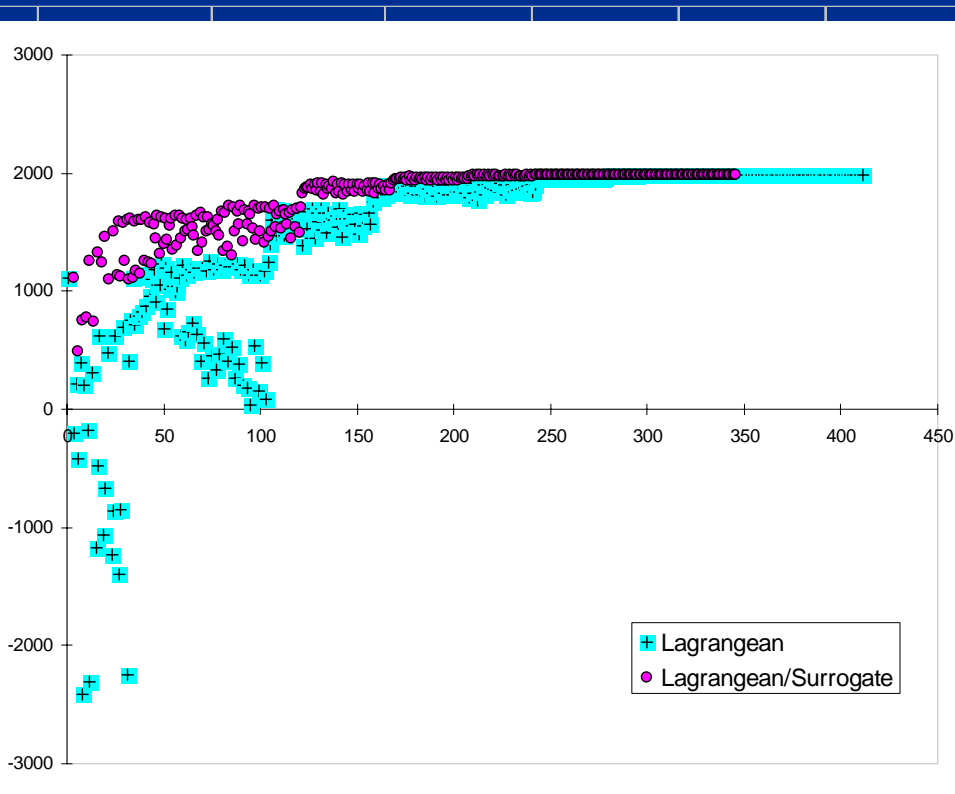
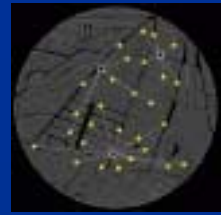
$t = 1 \rightarrow$ Relaxação Lagrangeana

$$v(D_t^\lambda) = \max_{t \geq 0} v(L_t SP^\lambda).$$

■ Relaxação
Lagrangeana/surrogate



Lagrangiana x Lagrangiana/surrogate



Seqüências ...

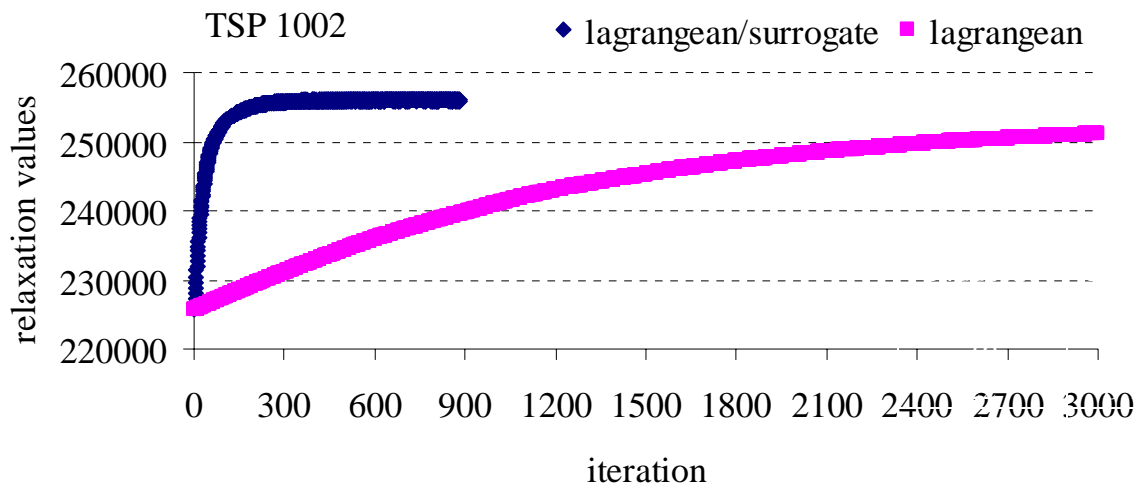
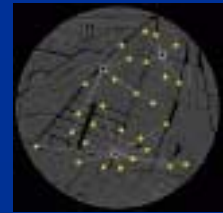
Lagrangena

e

Lagrangiana/surrogate

comportamento típico

Lagrangeana x Lagrangeana/surrogate



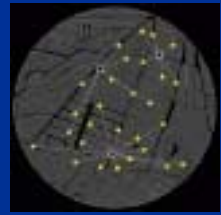
Caixeiro Viajante
1002 cidades

	gap (%)	Times (sec.)	Time (%)
	(0.1)	2. (1.03)	51
	(0.1)	9.1 (4.6)	51
	(0.3)	19. (8.)	42
	(0.3)	5. (5.)	100
	(2.)	27. (14.)	51
	(4.)	495. (392.)	92
	(1.)	4054. (997.)	24
1002	4. (2.)	36714. (1054.8)	2.8
1291	3. (3.)	13431. (3230.)	24
1304	5. (2.)	28094.3 (1511.)	5.3
1379	2. (2.)	9465.7 (3147.)	33
1655	3. (2.)	29368. (3029.)	10
1748	5. (2.)	48413. (1802.)	3.7
1889	5. (2.)	87568. (2275.4)	2.6
2152	2. (1.)	31334. (3648.)	11.6

P-medianas

Geração de colunas

(formul ações)



$$v(SP - Pmed) = \text{Min} \sum_{j=1}^m c_j x_j$$

Sujeito a

$$\sum_{j=1}^m A_j x_j = 1$$

$$\sum_{j=1}^m x_j = p$$

$$x_j \in \{0,1\}$$

$$S = \{S_1, S_2, \dots, S_m\}$$

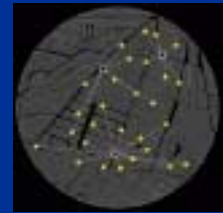
Conjunto de subconjuntos de N

$$c_j = \text{Min}_{i \in S_j} \left(\sum_{k \in S_j} d_{ik} \right)$$

$A = [a_{ij}]_{n \times m}$, is a matrix with $a_{ij} = 1$ if $i \in S_j$, and $a_{ij} = 0$ otherwise

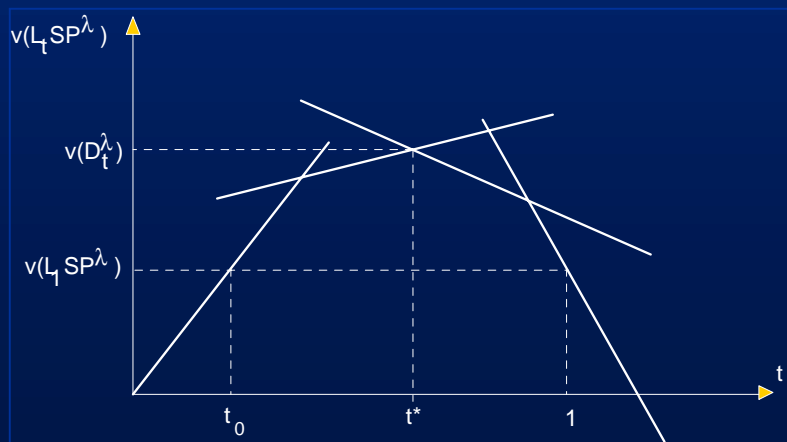
1	0	0	1	0	...
0	1	1	0	1	...
1	0	1	1	1	...
1	0	0	0	1	...
0	1	1	0	0	...
...

Lagrangiana/surrogate e Geração de colunas



$$v(\text{Sub}_t - \text{Pmed}) = \text{Min}_{i \in N} \left[\text{Min}_{y_j \in \{0,1\}} \sum_{j \in N} (d_{ij} - t \cdot \lambda_j) y_j \right]$$

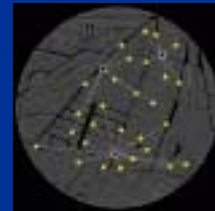
$t = 1 \rightarrow$ Custo reduzido



- Uso combinado de geração de colunas e relaxação Lagrangeana/surrogate

Algoritmo

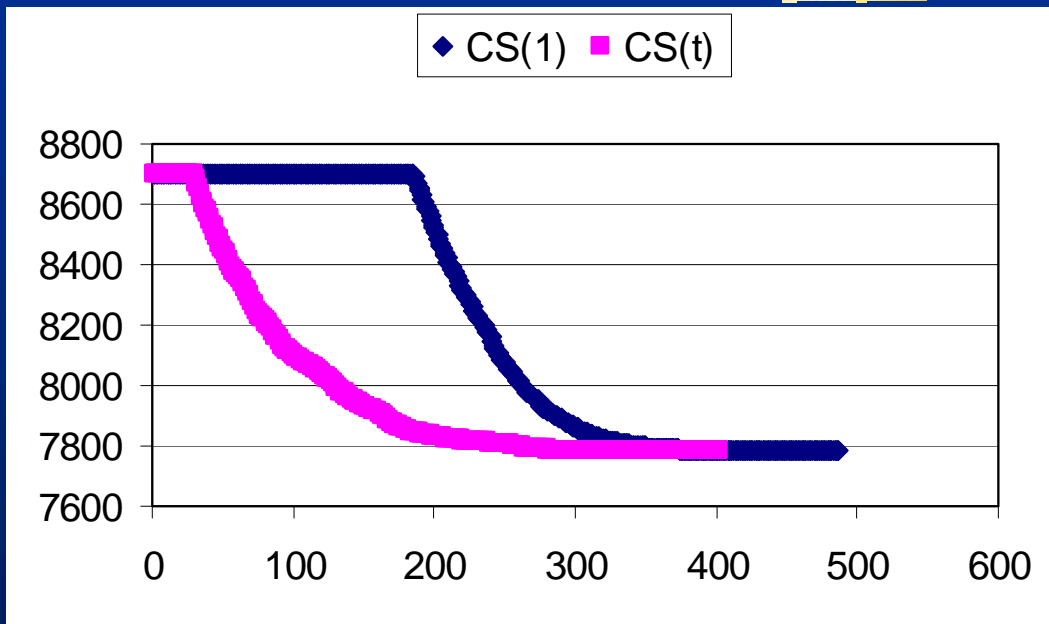
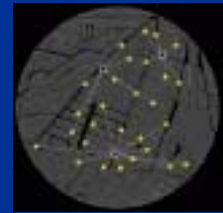
Geração de colunas



■ $CG(t)$

- | (i) Escolha um conjunto inicial de colunas para (SC-Pmed);
- | (ii) Resolva (SC=Pmed) usando CPLEX e retornando os multiplicadores duais π_j , $j=1, \dots, n$ e α ;
- | (iii) Resolva aproximadamente o dual local Lagrangeano/surrogate, retornando o melhor valor de t ;
- | (iv) Resolva o sub-problema correspondente incluindo em (SC-Pmed) as colunas satisfazendo $\left[\underset{y_j \in \{0,1\}}{\text{Min}} \sum_{j \in N} (d_{ij} - \pi_j) y_j \right] < \alpha$, $i=1, \dots, n$;
- | (v) Se não encontrar colunas no passo (iv) então pare;
- | (vi) Faça os testes para eliminar colunas e volte ao passo (ii)

Geração de colunas



CS(1) → geração de colunas

CS(t) → geração de colunas
combinado com
Lagrangeana/surrogate

Delete column i from the current ($SC-Pmed$) if $rc_i > rc_factor * mean_rc$.

rc_factor	$iter$	$columns$ $generated$	$columns$ $used$	gap_primal	gap_dual	$total$ $time$
0.5	403 (487)	18493 (47634)	7543 (7364)	– (–)	– (–)	619.63 (971.59)
0.4	414 (1000)	20395 (167247)	6627 (3270)	– (0.631)	– (4.635)	613.79 (1370.99)
0.3	400 (1000)	23521 (186267)	3886 (421)	–0.276 (11.171)	2.010 (65.181)	532.27 (905.67)

$mean_rc$

average of the reduced costs for the initial pool of columns

Geração de colunas

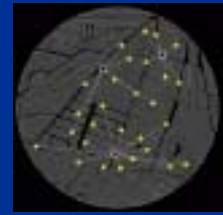


Table 4. Computational results for Pcb3038 instances ($rc_factor = 0.5$)

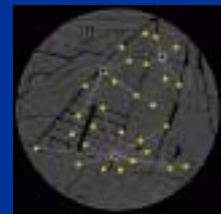
p	best known solution	iter	columns generated	columns used	gap_primal	gap_dual	total time
300	187723.46	79 (67)	96798 (111597)	40053 (39448)	-0.043 (-0.043)	0.044 (0.043)	19371.01 (36029.23)
350	170973.34	65 (53)	86113 (90651)	29179 (31664)	-0.044 (-0.044)	0.045 (0.044)	7077.99 (12905.94)
400	157030.46	53 (49)	77174 (94716)	22857 (30101)	-0.008 (-0.008)	0.008 (0.008)	2872.48 (5682.90)
450	145422.94	40 (41)	55870 (80631)	18662 (23767)	-0.052 (-0.052)	0.052 (0.053)	1288.56 (2568.56)
500	135467.85	34 (53)	45092 (79338)	16750 (22956)	-0.036 (-0.036)	0.036 (0.044)	716.78 (1425.33)

- rc_factor
- trade-off parameter to decide about available time and storage conditions

Table 5. Computational results for Pcb3038 instances ($rc_factor = 0.2$)

p	best known solution	iter	columns generated	columns used	gap_primal	gap_dual	total time
300	187723.46	617 (834)	958984 (1655221)	28718 (93535)	-0.043 (-0.043)	0.044 (0.043)	36333.01 (117707.31)
350	170973.34	393 (719)	576789 (1232357)	24475 (74005)	-0.044 (-0.044)	0.044 (0.044)	10823.10 (49874.03)
400	157030.46	235 (586)	330475 (1232440)	15973 (54724)	-0.008 (-0.008)	0.008 (0.008)	4529.20 (39883.02)
450	145422.94	155 (363)	176348 (843026)	13489 (20517)	-0.052 (-0.052)	0.052 (0.052)	2356.97 (12990.88)
500	135467.85	121 (210)	119884 (420737)	12997 (24254)	-0.035 (-0.036)	0.035 (0.036)	1682.15 (4340.33)

Método subgradientes x Geração de colunas



n	p	optimal solution	gap_primal		gap_dual		total time	
			LS	CG(t)	LS	CG(t)	LS	CG(t)
100	33	1355	–	–	–	–	0.58	0.48
200	67	1255	–	–	–	0.319	4.00	2.20
300	100	1729	–	0.093	–	0.049	16.78	4.94
400	133	1789	–	0.279	–	0.112	51.80	6.99
500	167	1828	–	0.128	–	0.285	127.60	12.95
600	200	1989	–	0.352	–	0.432	257.02	16.27
700	233	1847	–	0.135	–	0.379	482.97	24.20
800	267	2026	–	0.470	–	0.205	1374.74	28.99
900	300	2106	0.047	0.491	0.004	0.475	3058.65	45.60

OR - Library

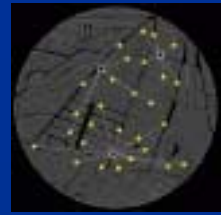
Comparação entre

CG(t) → Geração de colunas + Lagrangean/surrogate

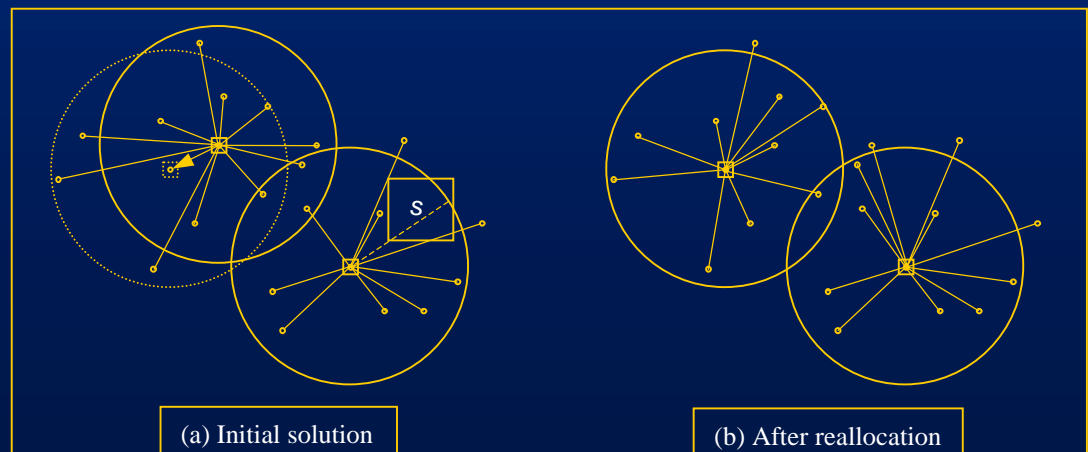
LS → Lagrangean/surrogate + método subgradientes

Busca Local

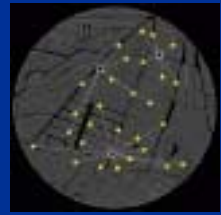
Localização-alocação



```
While ( $v_f$  decreases)
  For  $k = 1, \dots, p$ ;
    Interchange median and non-median nodes in cluster  $C^k$ ;
    Calculate the corresponding value  $v$  of the best reallocation;
    If  $v < v_f$ 
      Update the median node for cluster  $C^k$ ;
      Set  $v_f = v$ ;
    End If;
  End For;
End While;
```



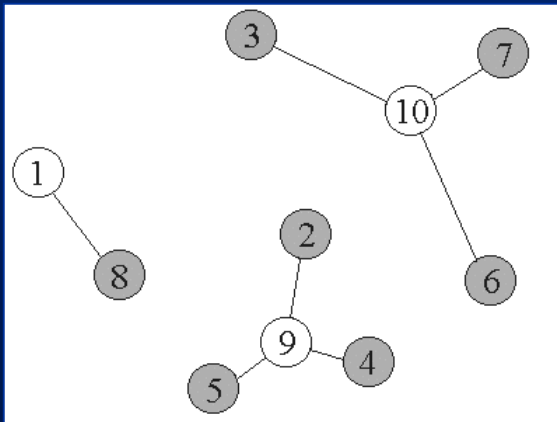
Algoritmo Genético Construtivo



Representação

Estruturas

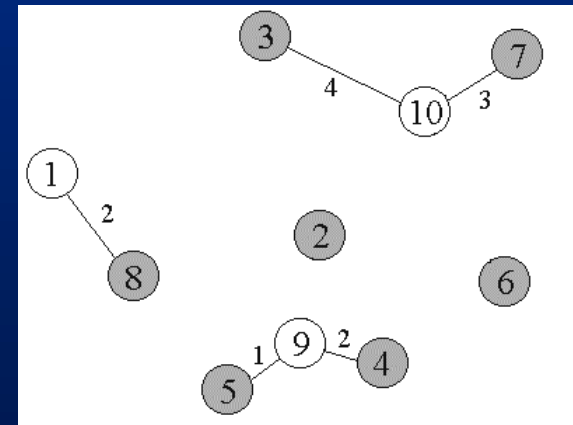
$$S_i = (1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1),$$



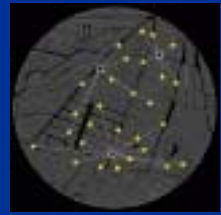
$$\begin{aligned} C_1(s_i) &= \{1, 8\}, \\ C_2(s_i) &= \{2, 4, 5, 9\}, \\ C_3(s_i) &= \{3, 6, 7, 10\} \end{aligned}$$

Esquemas

$$S_k = (1, \#, 0, 0, 0, \#, 0, 0, 1, 1),$$



$$\begin{aligned} C_1(s_k) &= \{1, 8\}, \\ C_2(s_k) &= \{4, 5, 9\}, \\ C_3(s_k) &= \{3, 7, 10\} \end{aligned}$$



Formulação geral

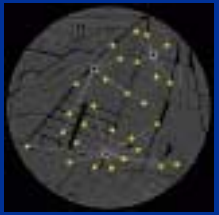
■ Bi-objective Optimization Problem (BOP)

■ $f: X \rightarrow \mathcal{R}_+$
and

■ $g: X \rightarrow \mathcal{R}_+$

■ $X = \{\text{estruturas e esquemas}\}$

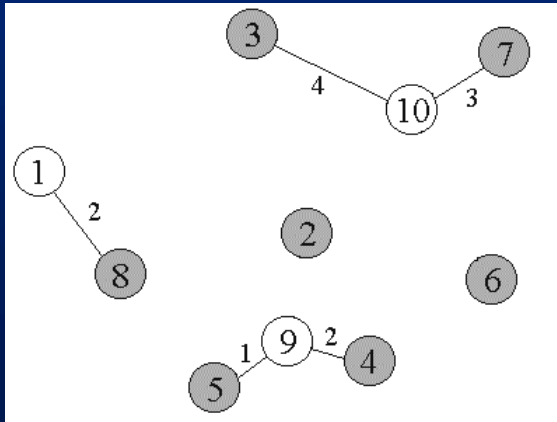
$$\begin{aligned} & \textit{Min} && \{g(s_i) - f(s_i)\} \\ & \textit{Max} && g(s_i) \\ & \textit{subject to} && g(s_i) \geq f(s_i) \\ & && \forall s_i \in X \end{aligned}$$



Funções f e g

■ Avaliação

- $V_1 = \{\zeta_1, \dots, \zeta_p\} \rightarrow$ o conjunto de índices dos *vértices sementes*

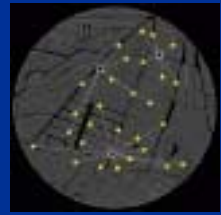


$$g(s_i) = \sum_{k=1}^p \sum_{j \in C_k(s_i)} d_{\zeta_k j}$$

$$f(s_i) = \sum_{k=1}^p \lambda_k \cdot [|C_k(s_i)| - 1]$$

$\lambda_k = \min_{j \in C_k(s_i)} \{\mu_{\zeta_k j}\}$

Evolução



■ O processo evolutivo

■ → *valores esperados*

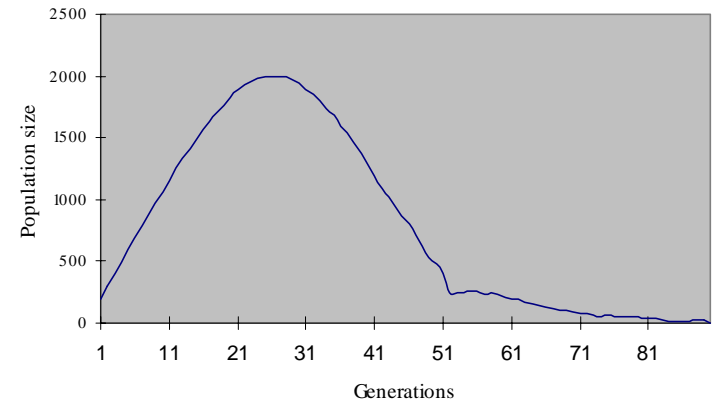
$$g_{\max} > \underset{s_i \in X}{\text{Max}} g(s_i),$$

intervalo → $d g_{\max}$, $0 < d \leq 1$.

■ limiar adaptativo de rejeição →

$$g(s_i) - f(s_i) \geq d g_{\max} - \alpha \cdot d [g_{\max} - g(s_k)]$$

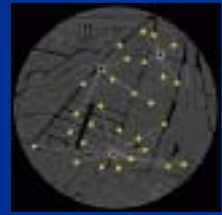
Figure 6: Population size by generation



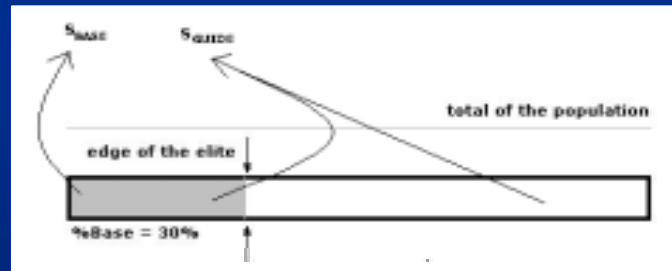
$$\alpha \geq \frac{d g_{\max} - [g(s_i) - f(s_i)]}{d [g_{\max} - g(s_k)]} = \delta(s_i)$$

rank

Recombinação e mutação



Seleção



Base-guide selection

mutação

recombinação

if $S_{base}(j) = S_{guide}(j)$ then $S_{new}(j) \leftarrow S_{base}(j)$

if $S_{guide}(j) = \#$ then $S_{new}(j) \leftarrow S_{base}(j)$

if $S_{base}(j) = \#$ or 0 and $S_{guide}(j) = 1$ then

$S_{new}(j) \leftarrow 1$ and $S_{new}(i) \leftarrow 0$ for some $S_{new}(i) = 1$

if $S_{base}(j) = 1$ and $S_{guide}(j) = 0$ then

$S_{new}(j) \leftarrow 0$ and $S_{new}(i) \leftarrow 1$ for some $S_{new}(i) = 0$

For each position j with label 1 *do*

For each position l with label 0 *do*

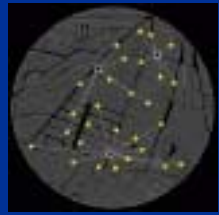
Interchange the labels on positions j and l generating an offspring S_{new} ; {offspring generation}

Interchange the labels on positions j and l ; {returning to the original S_{base} }

End_for

End_for

Algoritmo Genético Construtivo



Dados g_{max} and d ; $\alpha := 0$; $\varepsilon := 0.05$;

Inicializar P_α ;

{ população inicial }

Avaliar P_α ;

{ avaliação-fg }

Para todos $s_i \in P_\alpha$ computar $\delta(s_i)$

{ rank }

Fim Para

Enquanto (not condição de parada) faça

Para todo $s_i \in P_\alpha$ satisfazendo $\alpha < \text{faça}$

{ teste de evolução }

$\alpha := \alpha + \varepsilon$;

Selecionar P_α from $P_{\alpha-\varepsilon}$;

{ operador de reprodução }

Recombinar P_α ;

{ operadores de recombinação }

Avaliar P_α ;

{ avaliação-fg }

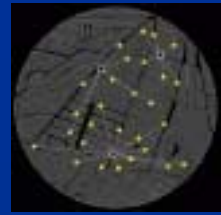
Fim Para

Para todo novo $s_i \in P_\alpha$ computar $\delta(s_i)$ *{ rank }*

Fim Para

Fim Enquanto

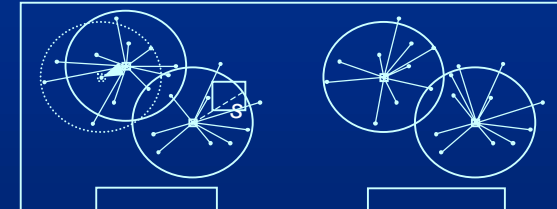
AGC x Lagsur



■ Comparações

AGC Lorena & Furtado (2000)

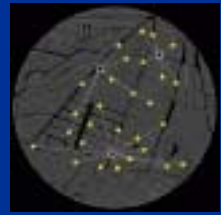
<i>medianas</i>	<i># nos</i>	<i>AGC</i>	<i>Lagsur</i>	<i>iterações</i>	<i>tempo(s)</i>
5	324	122518	122518	89	359
10	324	79845	79256	100	690
20	324	55610	54533	100	813
50	324	32098	32101	100	1034
108	324	18918	19683	100	1132
5	818	605232	605855	100	1520
10	818	383527	385371	100	1180
20	818	251631	251717	100	1191
50	818	148145	149251	100	956
5	3282	6381109	6381119	100	3642
10	3282	3912443	3914249	100	6321
20	3282	2348723	2350502	100	10156
50	3282	1294561	1308957	100	24531



AGC com mutação de localização-alocação

<i>medianas</i>	<i># nos</i>	<i>AGC</i>	<i>Lagsur</i>	<i>iterações</i>	<i>tempo(s)</i>
5	324	122518	122518	81	361
10	324	79525	79256	100	720
20	324	54812	54533	100	891
50	324	32098	32101	100	1114
108	324	18850	19683	100	1282
5	818	605041	605855	100	1690
10	818	382845	385371	100	1210
20	818	251595	251717	100	1291
50	818	147008	149251	100	1072
5	3282	6381092	6381119	100	4151
10	3282	3912104	3914249	100	7531
20	3282	2346413	2350502	100	10890
50	3282	1290104	1308957	100	25639

Downloads



■ Artigos

- <http://www.lac.inpe.br/~lorena/public.html>

■ Integrações

- <http://www.lac.inpe.br/~lorena/ArsigIndex.html>

■ Dados

- <http://www.lac.inpe.br/~lorena/instancias.html>

